Swaine, 146 *New Bond Street, London.*

W. Riall Sankey

PRESIDENT.

(THE) INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1920, v. 2

JULY–DECEMBER.

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The Institution of Mechanical Engineers

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)
Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)
Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)
John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)
James Kennedy, 1860. (*Deceased* 1886.)
The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)
Robert Napier, 1863–65. (*Deceased* 1876.)
John Ramsbottom, 1870–71. (*Deceased* 1897.)
Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75. (*Deceased* 1903.)
Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)
John Robinson, 1878–79. (*Deceased* 1902.)
Edward A. Cowper, 1880–81. (*Deceased* 1893.)
Percy G. B. Westmacott, 1882–83. (*Deceased* 1917.)
Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)
Jeremiah Head, 1885–86. (*Deceased* 1899.)
Sir Edward H. Carbutt, Bart., 1887–88. (*Deceased* 1905.)
Charles Cochrane, 1889. (*Deceased* 1898.)
Joseph Tomlinson, 1890–91. (*Deceased* 1894.)
Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)
Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.
E. Windsor Richards, 1896–97.
Samuel Waite Johnson, 1898. (*Deceased* 1912.)
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900. (*Deceased* 1913.)
William H. Maw, LL.D., 1901–02.
J. Hartley Wicksteed, 1903–04. (*Deceased* 1919.)
Edward P. Martin, 1905–06. (*Deceased* 1910.)
T. Hurry Riches, 1907–08. (*Deceased* 1911.)
Sir John A. F. Aspinall, M.Eng., 1909–10.
Edward B. Ellington, 1911–12. (*Deceased* 1914.)
Sir H. Frederick Donaldson, K.C.B., 1913–14. (*Deceased* 1916.)
W. Cawthorne Unwin, LL.D., F.R.S., 1915–16.
Michael Longridge, C.B.E., 1917–18.
Edward Hopkinson, D.Sc., M.P., 1919.

The Institution of Mechanical Engineers.

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1920.

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CAPTAIN H. RIALL SANKEY, C.B., C.B.E., R.E., ret., ... London.

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MARK H. ROBINSON, ... London.
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DONALD B. MORISON, ... Hartlepool.
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ENG. VICE-ADMIRAL SIR HENRY J. ORAM, K.C.B., F.R.S., ... London.
WILLIAM H. PATCHELL, ... London.
LOUGHNAN ST. L. PENDRED, ... London.
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F. H. NORWOOD.

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The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W. 1.
Telegraphic Address:—*Mech, Parl, London.* Telephone:—*Victoria*, 4564.

The Institution of Mechanical Engineers.

PROCEEDINGS.

July 1920.

The Summer Meeting of the Institution was held in Lincoln, commencing on Tuesday, 20th July 1920, at Ten o'clock a.m. The President, Captain H. Riall Sankey, C.B., C.B.E., late R.E., took the Chair in the Theatre of the Municipal Technical School, after the Council and Members of the Institution, and Ladies, had been welcomed by the Right Worshipful the Mayor of Lincoln, Alderman H. A. Cottingham, and the Members of the Lincoln Reception Committee.

The Right Worshipful the Mayor of Lincoln (Alderman H. A. Cottingham), in giving a civic welcome to the Institution on its visit to Lincoln, expressed his great pleasure at the fact that ladies were present at the gathering. Their presence relieved the somewhat severe aspect of the building, and added a glamour to the Meeting which otherwise would have been absent. He was present as the representative of the citizens of Lincoln, to welcome to their ancient city the members of the Institution. Lincoln was a city of renown, for two or three reasons. First of all it was known throughout the civilized world for its glorious Cathedral, and in the second place for the fame of its manufactures. There was scarcely a region of the world, civilized or uncivilized, to which the machinery of Lincoln had not penetrated, in the way of

(The Mayor of Lincoln.)
agricultural machinery, mining machinery, or plantation machinery. He did not propose to dwell upon the antiquities or history of Lincoln, because his friend, Col. Mansel Sympson, would give a full account of them in the Lecture he was about to deliver. He only desired to say that the rise and progress of Lincoln had been synonymous with that of the works, until it had become one of the largest cities in this great country. Not satisfied with its being a fairly large city, the citizens had been induced to ask Parliament to allow them to extend their boundaries. His friend the Town Clerk, who had written a résumé of the history of Lincoln, mentioned that several Parliaments had been held in the city, over which Kings had presided, but he ventured to say that no Parliament had ever been held in the city which was of more importance to the city itself than the Parliament which was assembled in the Meeting that morning. He was happy to say that, in addition to the Mayor and other Members of the Corporation, many of the other leading citizens of Lincoln were present to welcome the members of the Institution to Lincoln. He was speaking of what he knew when he said that the relations of the engineers of Lincoln and the Corporation had always been of the most cordial nature, and they had worked, he believed, for the mutual advantage of the city. Many leading engineers of Lincoln had occupied the position that he now had the honour to fill, namely, Mr. Nathaniel Clayton in 1856, his partner, Mr. Joseph Shuttleworth, in 1858, Alderman William Foster in 1863, Mr. Joseph Ruston in 1869, and later on, in 1906, perhaps for the first time, the son of a former Mayor, Col. Joseph S. Ruston, was elected to the position. He made those remarks in order to emphasize how intimately associated the engineering works and their owners were with the Corporation. Col. Ruston's year of Office was a memorable one. The Royal Agricultural Show occurred during his mayoralty, and His Majesty King Edward VII visited the city on that occasion. There were other members of the Institution who had been associated with the Corporation to whom he wished to refer. Some years ago the city was anxious to obtain a better water supply, and the man in the Corporation who helped more than anybody else, except the

engineer, to obtain what he believed was one of the best and purest water supplies in the country, was a Member of the Institution, Mr. F. H. Livens. All the members of the Corporation were sorry when Mr. Livens decided to leave them, but they had some consolation in the fact that another member of the Institution had become a member of the Corporation, and that gentleman was a valuable asset, not only to the Corporation, but to the city generally—he referred to his friend, Councillor George Robson. In conclusion, he could only say again, on behalf of the city of Lincoln, that he welcomed the members of the Institution most heartily to the ancient borough of Lincoln. He wished them happy hours in their meetings and happier hours still in their recreation.

The President, in the name of the Institution, thanked His Worship the Mayor for the very warm welcome he had accorded to the members on the occasion of their visit to the ancient City of Lincoln. It was only necessary to look at the long list of names of ladies and gentlemen who formed the Reception Committee to know that a very hearty and cordial welcome would be extended to the Institution. He felt quite sure that, if only the Meeting was favoured with fine weather, the members could look forward to a most profitable and agreeable time during their stay at Lincoln. He said "profitable" because they would make new friendships, renew old friendships, and also see some most interesting Works, and the information that they would thus gather would be of inestimable value to the Institution as a whole, to the members in particular, and through them to the Country generally.

He had been very pleased to hear from the Mayor the intimate connexion that existed between the Corporation and the Works. Such connexion must be of the greatest value and must further the usefulness of the Works in many ways. It was interesting to note that thirty-five years ago, beginning on 4th August 1885, the Institution held a Meeting at Lincoln, under the Presidency of the late Mr. Jeremiah Head, while Mr. Francis Jonathan Clark was the Mayor. Mr. Head in his speech referred to the attractions of Lincoln, not only its Cathedral and Castle and the old Roman

(The President.)
remains, but the important Engineering Works of world-wide celebrity. Those words were true at the present time, with the added importance that during the War the engineering firms at Lincoln were amongst the foremost in producing munitions of war. He knew that personally, because he visited several of these Works in order to ascertain what would be the value to those firms, after the War was over, of the plant that had been put down for war purposes. In many cases this post-war value was not much, but the plant had done its duty for the country. It would weary the members if he mentioned the many kinds of munitions of war that were made in Lincoln, and he did not propose to do so, but he could not help referring to the "Tanks."

The present Meeting was attended by 195 members who were accompanied by 63 ladies. In 1885, 224 members attended the Meeting, but it was not stated in the Proceedings whether any ladies were present or not. Since 1885 the Institution had grown enormously, the membership then being about 1,200, while at the present time it was over 7,000. He thought one reason why there were not more members present was the difficulty of railway communication. The Council did its very best (and that was a good deal, because there were several railway engineers on the Council) but they were unable to get any facilities for railway travelling. He hoped the Mayor would not consider the shortness of his speech as in any way a measure of the warmth of the thanks of the members for the very hearty welcome that had been extended to them. He again thanked the Mayor most sincerely for the very kind way in which he had received them.

A Lecture on "ROMAN LINCOLN" was then delivered by Lieut.-Colonel E. MANSEL SYMPSON, M.A., M.D., F.S.A.

The Minutes of the previous Meeting, held on 23rd April 1920, were taken as read, and confirmed.

The PRESIDENT announced that the following 177 Candidates had been found to be duly elected:—

MEMBERS.

ADAMS, JOHN WILLIAM,	Leeds.
AGAR, ALFRED,	Belfast.
AIKMAN, ANDREW, M.B.E.,	Bedford.
BLACK, JAMES,	Paisley.
BLOW, JOHN EASTMAN, M.C.,	London.
BONE, VICTOR WILLIAM,	Ipswich.
BROWN, ALEXANDER,	Belfast.
CALLANDER, JAMES,	Barrow-in-Furness.
CHELL, EDWARD ARTHUR,	London.
COLE, HAROLD LINTER,	Simla.
COLLETT, CHARLES BENJAMIN, O.B.E.,	Swindon.
COX, FREDERIC ALBERT,	Cochin, India.
CURRIE, THEODORE,	Liverpool.
DREW, EDWARD ARTHUR HOLBOROW,	Bedford.
ELLIOTT, GEORGE GOODBAN,	Pretoria.
FLEMING, FREDERICK ALEXANDER, M.B.E.,	Grimsby.
FRASER, JOSEPH SMITH,	Aberdeen.
GRAY, EDWARD HODSON,	Bloemfontein.
GROOME, SEPTIMUS FREDERICK,	Bedford.
HALE, KYNASTON OVERSTOW,	London.
HIAM, ROBERT WOOD,	Kuala Lumpur.
HOWLETT, HARRY RANSOME,	Bedford.
HOWSIN, CECIL GASCOYNE,	London.
JAMES, GEORGE LLEWELLYN DENTON,	Wellington, N.Z.
JEBOULT, WILLIAM ALEXANDER,	Birmingham.
JOYCE, HARRY,	Birmingham.
KENWORTHY, ALBERT RYDER, Major,	Huelva.
LUMSDEN, THOMAS,	Gateshead.
LYLE, DAVID LAIRD,	Hong Kong.
MARSHALL, CHARLES FREDERICK BERTRAM,	London.
MAYNE, ROBERT NEWELL,	Redditch.
MORSE, RICHARD VICTOR, Major, D.S.O.,	Sydney, N.S.W.
MORTIBOY, JOHN EDWARD,	Coventry.
MOSSCROP, GILBERT WILLIAMS,	London.
OKELL, ROBERT,	Durban.
OWEN, ALFRED DUDMAN, Major, D.S.O.,	London.
OXLIN, HERMAN,	Bedford.
POMEROY, CLAUD CHARLES,	London.
ROGERS, FRANK, D. Eng.,	Sheffield.
RUSSELL, MATTHEW,	Greenock.
SMITH, WILLIAM GROSVENOR,	Manchester.
SPURGEON, CHRISTOPHER EDWARD,	Lahore.
STRICKLAND, FREDERICK WILLIAM,	Bedford.
SWIFT, ALFRED MARMADUKE,	Lincoln.
TETLEY, MICHAEL HUBERT,	Bedford.
TITT, ALEC JOHN BUCKERIDGE,	Warminster.
TOMLINSON, TOM ASHTON,	Manchester.
VOSE, HENRY JAMES,	London.
WALSH, JULIAN NOEL,	Southampton.
YOUNGER, WILLIAM GRAY,	Aberdeen.
ABBOTT, WILLIAM,	Rosyth.

ASSOCIATE MEMBERS.

ALCOCK, MASON, ... Belfast.
ARNOLD, WILLIAM HENRY, ... London.
BATE, STEPHEN CONRAD CLAVELL, ... Selby.
BAXTER, CHARLES, ... Shipley.
BEILL, JOHN, ... Edinburgh.
BRIGGS, HENRY STACPOOLE, O.B.E., Major, R.E. . Gosport.
BROOKS, WILLIAM EDWIN, ... London.
BUXTON, JOHN, ... Birmingham.
CARDER, CHARLES HENRY, ... Birmingham.
CASE, HENRY GRIFFITHS, ... Great Yarmouth.
CHAMBERS, HAROLD, ... Dudley.
COCKERILL, JAMES FRANK, ... London.
DAVIES, HUGH, ... Lucknow.
DAY, ARTHUR OSBORNE, ... Bath.
DICKIN, GEORGE WILLIAM, ... Birkenhead.
DOWLING, ROBERT JOHN, ... Dublin.
DRUMMOND, WALTER JAMES, ... Newcastle-on-Tyne.
DUNK, NORMAN ALFRED, Lieut., R.A.O.C., . . London.
EVANS, ALFRED GEORGE, ... Wolverhampton.
GADSDEN, RODERICK FRASER, ... Birmingham.
GRANTHAM, LEONARD RICHARD, ... Lincoln.
HALL, THOMAS, ... Ceylon.
HAMERSLEY, HAROLD ST. GEORGE, Major, R.A.S.C., . Claydon.
HANCOX, JAMES GREGORY, ... Darlaston.
HARDING, WILLIAM CHORLEY, ... Warrington.
HARRIS, FRANK WILLIAM, ... Swindon.
HARRISSON, FREDERICK GEORGE, ... Yeovil.
HART, EDWIN, ... Grimsby.
HAYWARD, WALTER CHARLES GEORGE, ... Twickenham.
HEAYS, HARRY CECIL, ... Wellington, N.Z.
HESKETH, JOHN, ... Stafford.
HILL, SYDNEY, Captain, R.E. (T.F.), . . . Oakham.
IYER, VEERAPPANCHATRAM GANESH, ... Bangalore.
JARVIS, EDWARD JAMES, ... Enfield.
JEFFERSON, FRANK HARVEY, Eng. Lieut., R.C.N., . Halifax, N.S,
JENNINGS, MARK, ... Bury St. Edmunds.
KING, HENRY JOHN, ... Huddersfield.
LANGFORD, CECIL GEORGE, ... Warrington.
LANGLEY, ARTHUR, ... Leeds.
LAWLER, JOHN ROSE, ... Gorakhpur.
LAYTON, THOMAS WILLIAM, ... Portsmouth.
LEGAT, EDDOWES STUART, ... Birmingham.
LIDSTONE, ALLAN, ... London.
LIVERSIDGE, WILLIE, ... Sheffield.
LOWE, HERBERT, ... Birmingham.
MCQUAIGUE, FREDERICK ERNEST, Eng. Sub-Lieut. R.N.R., ... London.
MARSHALL, GODFREY EDWIN BENTALL, Capt. R.A.S.C., Salisbury.
MILLER, WILLIAM ERNEST, ... Portsmouth.
MONTAGU, AINSLEY MARSHALL RENDALL, Capt., R.A.F. London.
OGLE, ERNEST JAMES, ... Manchester.
ORMOND, JOHN CALVERT, ... Lincoln.
OSMOND, REGINALD WALTER, ... Woolwich.
PARKER, THEODORE HENRY GEORGE, ... Letchworth.
PAUL, HERBERT JOHN, ... Georgetown, B.G.
PHILLIPS, HUBERT CYRIL, ... Letchworth.

REID, WILFRID THOMAS, ... Bristol.
RENDLE, FRANCIS CHARLES, ... Devonport.
SCOTT, FRANK DOUGLAS, Major, R.A.O.C., . . Alexandria.
SCOTT, WILLIAM HILL, ... Edinburgh.
SPARKS, ALGERNON CHARLES, M.C., ... London.
STANTON, ALBERT LENNOX, ... Bristol.
STURGEON, ROBERT ALEXANDER, ... Leeds.
TAYLOR, CHARLES HAROLD, ... London.
TAYLOR, GEORGE EDWARD, ... London.
THOMPSON, RALPH WILLMETT, ... Leith.
THORNHILL, GEORGE COLLENETTE, ... London.
URQUHART, ROBERT NICOL, ... Newcastle-on-Tyne.
WELLINGHAM, HERBERT JOHN, M.C., . . . London.
WHITFIELD, WESLEY, JUN., ... Stroud.
WHITTAKER, HARRY, ... London.
WILSON, FRANK BAXTER, ... Darlaston.
WOOD, THOMAS HERBERT, ... Newport, Mon.
YATES, HARRY, ... Stockport.

ASSOCIATES.

MAXIM, JAMES LEONARD, ... Rochdale.
WARREN, ARTHUR GEORGE, ... Hong Kong.

GRADUATES.

ANGRAVE, FREDERICK WILLIAM, ... Bath.
BALL, WILLIAM, ... Swanley.
BARKER, LLEWELLYN HEDMONDT, ... London.
BARNES, VICTOR FREDERICK WALTER, . . . Derby.
BARTLETT, REGINALD CHARLES, ... London.
BERG, CLEMENT LEONARD, ... London.
BEST, FREDERICK ARNOLD, ... Eyam.
BONNYMAN, JOHN, ... Arbroath.
BRADING, HARRY ARCHIBALD, ... Wolverhampton.
BRIGGS, ALFRED GEORGE ERNEST, ... Sheffield.
DEACON, FRANK EDWIN, ... Derby.
DIMMOCK, GEOFFREY FREDERICK, ... Harrogate.
FENNER, ALEXANDER CHRISTIAN, ... London.
FULLER, ARTHUR HEDLEY, ... London.
GEARING, SYDNEY JAMES, ... Egremont.
GREEN, ERIC STEWART, ... Dartford.
GREENLAND, GEORGE WILFRID, ... Newport, Mon.
GREGORY, CECIL, ... London.
GRIFFITH, ARTHUR CECIL, ... Derby.
HEY, ISRAEL, ... Hyde.
HINES, ALFRED EDGAR, ... Birmingham.
HUTSON, FRANCIS CHALLENOR, ... Derby.
INNES, ROBERT KNIGHT, ... Swindon.
IRWIN, HARLOW, ... Manchester.
JARVIS, HORACE, ... Kingston-on-Thames.
JENNINGS, RICHARD ROBERTSON, ... London.
JONES, DOUGLAS CARTER HARWOOD, . . . Southampton.
KYTE, GORDON WILLIAM, ... Whitchurch.
LATHAM, ERNEST JOSEPH, ... Stafford.
MACDONALD, DONALD HERBERT, ... Leagrave.
MINES, RICHARD, ... Loughton.

MOORE, AINSLIE GEORGE,	London.
MORRIS, WILLIAM HAROLD,	Sunderland.
PARISOT, EUGENE OSCAR WILLIAM LA VALETTE,	Whyteleafe.
PILGRIM, HUGH FRERE,	Derby.
RAMSDEN, HARRY WARWICK,	Wakefield.
REEVES, NORMAN,	London.
REID, HENRY WILLIAMS,	Aberdeen.
ROBB, WILLIAM GEORGE,	Aberdeen.
ROLLINSON, ERIC WILLOUGHBY,	Ilford.
RUSSELL, ANDREW BLACK,	Dundee.
SAWYER, WILLIAM HARRY,	Manchester.
SILK, PHILIP RICHARD GEORGE,	London.
SKINNER, THOMAS VICTOR,	Birmingham.
SLADE, TOM,	Eastbourne.
STACEY, HERBERT RICHARD,	Sunderland.
STILWELL, REGINALD PEEL,	Mildenhall.
WALKER, PERCY STUART,	London.
WATT, EDWARD,	Aberdeen.
WEISS, ROBERT GEORGE ALBERT,	London.
WELCH, THOMAS BASIL,	Brighton.

The PRESIDENT announced that the following 42 Candidates had been elected by the Council under the new By-laws 19–22:—

ASSOCIATE MEMBERS.

ATTOCK, GEORGE HENRY,	London.
BOTTOMLEY, CYRIL,	Chester.
BROWN, HERBERT,	Cardiff.
CAWLEY, GEORGE MIDDLETON,	Stockport.
DERHAM, ARTHUR CORNELIUS,	Mistley.
FOX, CHRISTIAN ERIC,	London.
FRANCIS, WILLIAM ERNEST,	Loughor.
FRANKLIN, ARTHUR CHARLES,	London.
GORVIN, SIDNEY ERNEST,	London.
HEBBLETHWAITE, ARTHUR CECIL,	Plymouth.
HIGSON, FRANK,	Selby.
INGHAM, CHARLES WILLIAM,	Birmingham.
LIVINGSTONE, ROBERT,	Preston.
LOWE, JOHN WILLIAM,	Preston.
MAJOR, STEPHEN VINE,	London.
MARSH, WILLIAM RANDALL,	Barrow-in-Furness.
MARTIN, QUINTIN YOUNG,	Barrow-in-Furness.
ORR, ANDREW JENKINS,	London.
PARTRIDGE, EDWARD HENRY WILLIAM, O.B.E., Major, R.A.S.C.,	Rouen.
PAYNE, WILLIAM ERNEST,	London.
PERRIN, MICHAEL,	London.
PRUNELL, THOMAS LAMB,	London.
SIMS, JOHN WALTER,	London.
SPROSON, HERBERT,	Sheffield.
SUTHERLAND, STEWART NICOLL,	Glasgow.
TOOBY, CHARAES FREDERICK,	Coventry.
TREEBY, WILLIAM VINCENT,	Paris.

WELCH, WALTER,	Huddersfield.
WILSON, GEORGE HUMPHREYS,	London.
WOODROW, ROBERT HENRY,	Rosyth.

GRADUATES.

AYERST, WILLIAM GEOFFREY,	London.
BARTLETT, OSWALD WILLOUGHBY,	Henley-on-Thames.
BOLTON, LEONARD GEORGE,	London.
BURTON, JOHN DENIS,	London.
CLARK, HUGH CECIL STUART,	London.
COYSH, HUMPHREY CECIL, Sub-Lieut., R.N.,	London.
DONALDSON, ARTHUR JAMES,	London.
GOWRING, HUMPHREY JOHN,	London.
KING, GEOFFREY BURTON,	London.
MOUL, FRANK DOUGLAS,	London.
RUSBRIDGE, CHARLES EDWARD,	London.
VARIAN, EUGENE NICOLOVIUS,	London.

The PRESIDENT announced that the following 13 Transferences had been made by the Council:—

Associate Members to Members.

CHIPPERFIELD, WALTER,	Romford.
CURR, THOMAS, O.B.E.,	London.
EMBLETON, CHARLES ARNOLD,	London.
EMERY, JAMES INMAN,	Erith.
HILLHOUSE, JOHN PATON,	Birmingham.
HOPKINS, EDMUND CHARLES,	London.
HOPKINS, GEORGE ARTHUR,	London.
MILLER, JAMES,	Derby.
OSBORN, HARRY FORTESCUE,	Birmingham.
ROBERTSON, ANDREW,	Bristol.
ROBERTSON, GEORGE WALLACE,	Preston.
THORPE, WILFRED BERTRAM,	London.
YATES, ALFRED ERNEST,	London.

The following Papers were read in abstract and discussed:—

"Recent Excavator Practice"; by F. H. LIVENS and W. BARNES, *Members*, of Lincoln.

"Road Transport by Steam-Vehicles"; by P. W. ROBSON, O.B.E., of Lincoln.

At a Quarter to One o'clock p.m., the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Theatre of the Municipal Technical School, Lincoln, on Wednesday, 21st July 1920, at Ten o'clock, a.m.; Captain H. RIALL SANKEY, C.B., C.B.E., late R.E., in the Chair.

The following Papers were read in abstract and discussed:—

"Some Lincolnshire Oil-Engines"; by F. H. LIVENS, *Member*, of Lincoln.

"The Human Factor in Industry"; by ALEXANDER RAMSAY, of Lincoln.

"The Uniflow Steam-Engine"; by F. B. PERRY, *Member*, of Lincoln.

"Note on New Power Station for Messrs. Marshall, Sons and Co., Gainsborough"; by F. J. CRIBB, *Member*, of Gainsborough.

THE PRESIDENT moved the following Votes of Thanks, which were carried by acclamation:—

"That the best thanks of the Members of The Institution of Mechanical Engineers, in this Meeting assembled, be given:—

To the Right Worshipful THE MAYOR OF LINCOLN, Alderman H. A. COTTINGHAM, Lieut.-Colonel J. S. RUSTON, *Chairman*, and the Members of the LINCOLN RECEPTION COMMITTEE, for their Welcome of the President, Council and Members of the Institution to Lincoln; for the provision of conveyances for the Visits on Tuesday afternoon, and for other facilities and arrangements for the Meeting.

To the CITY OF LINCOLN EDUCATION AUTHORITY; for kindly placing the Lecture Theatre, Gymnasium, and other rooms in the Municipal Technical School at the disposal of the Institution for the Meetings and other purposes.

To Messrs. CLAYTON AND SHUTTLEWORTH, Messrs. JOHN LYSAGHT, Messrs. ROBEY AND CO., and Messrs. RUSTON

AND HORNSBY; for facilities and hospitality in connexion with the Visits to their Works.

To the Right Worshipful THE MAYOR AND MAYORESS OF NEWARK, Councillor and Mrs. H. E. BRANSTON, for receiving the Members and Ladies in the Town Hall; and to the NEWARK RECEPTION COMMITTEE, for the arrangements for the Visit to Newark.

To the NEWARK ENGINEERING FIRMS; for kindly inviting the Members and Ladies to Luncheon and Tea, and for other facilities in connexion with the Visit to Newark.

To Messrs. MARSHALL, SONS AND Co., for the arrangements and facilities for the Visit to Gainsborough, and for kindly inviting the Members to Luncheon; and to Sir HICKMAN B. BACON, Bart., for granting permission for the Members to Visit the Old Hall, Gainsborough.

To the LINCOLN ENGINEERING FIRMS; for kindly inviting the Members and Ladies to a Reception in the County Assembly Rooms, Lincoln.

To Messrs. CLARK'S CRANK AND FORGE Co., Messrs. WILLIAM FOSTER AND Co., THE FRODINGHAM IRONSTONE MINES, and Messrs. ROSE BROTHERS; for arrangements connected with the organized Visits to their Works.

To the various PROPRIETORS OF PLACES OF ENGINEERING INTEREST in Lincoln, Gainsborough, Newark, Scunthorpe and Coventry; for their kindness in throwing open their Works for the Visits of Members.

To the CITY OF LINCOLN CORPORATION; for kindly providing special tramcars on Wednesday afternoon.

To the LADIES' COMMITTEE, for arranging for the entertainment of the Lady Visitors during the Business Meetings; to Mr. P. W. ROBSON, O.B.E., and Mrs. ROBSON, for kindly inviting the Ladies to a Garden Party at Dunelm House; and to Lieut-Colonel E. MANSEL SYMPSON, M.A., M.D., F.S.A., for kindly conducting the Ladies on their Visit to Old Lincoln.

To the Very Reverend DEAN OF LINCOLN, Dr. T. C. FRY,

and to the Venerable Archdeacon W. J. CONYBEARE, M.A., for kind invitations to Visit the Cathedrals of Lincoln and Southwell respectively; and to the Right Reverend THE LORD BISHOP OF LINCOLN, Dr. W. SHUCKBURGH SWAYNE, and Mr. A. SHUTTLEWORTH, D.L., J.P., for kindly permitting the Ladies to Visit portions of Roman Lincoln.

To the Honorary Local Secretary, Mr. ALFRED E. COLLIS, for planning the various Visits, etc., and for the admirable arrangements which his forethought and energy have provided for each day of the Meeting; and to Mr. F. H. LIVENS, Mr. HERBERT J. MARSHALL, and Mr. EDWARD JOSSELYN, for their kind assistance in the detailed arrangements."

The Meeting terminated at a Quarter to One o'clock, p.m.

The Meeting was attended by 175 Members and 20 Visitors; and 63 Ladies were also present.

ROMAN LINCOLN.

LECTURE.

By Lieut.-Col. E. MANSEL SYMPSON, M.A., M.D., F.S.A., of Lincoln.

There is much in the name Lincoln. A Roman geographer, Claudius Ptolemæus, who flourished about the year 139 A.D., states that the British Tribe of the Coritani, who inhabited what are now the counties of Lincolnshire, Leicestershire, Rutland, Nottinghamshire, Warwickshire, and Derbyshire, had for their two chief towns Lindum, afterwards Lincoln, and Rage or Ratae, afterwards Leicester. Some authorities have traced in the word Lindum, two Celtic words, Lin meaning a lake or pool, and Don, latinized into Dum, meaning a hill fort, which, if the British City was—the most likely site for it where the Castle is now—would be a most suitable name for it—the hill fort by the water—as there must have been a large tract of water between Lincoln and Saxilby, and probably another great pool south-east of the city. But Mr. Henry Bradley, one of the editors of the "New English Dictionary," tells me that the Welsh Llyn (as in Llyn Ogwen, etc.) is the modern form of Lindon, having lost the termination. We also know that Lindum was a colony, and the Latin name Lindum Colonia was pronounced Lindocolina by the British, and later on Lindcyllene by the Anglo-Saxons, according to the customary changes of letters in these languages. And sometimes Lindocyllanceaster,

the terminations ceaster, chester, or cesta, being applied to Roman fortifications wherein stone was at least partially used. By the Normans in Norman-French the city was always called Nicole, by a curious transposition, and in Latin, Lincolnia, whence the change to its present name is easy. And it is remarkable that, with the exception of Cologne, Köln on the Rhine (Colonia Agrippina), Lincoln is the only city in Europe which bears evidence of its having been a Roman colony in its name.

Walls and Ditches (*Plate* 1).—The first Roman City of Lindum Colonia embraced an area of about 38 acres on the summit of the cliff, and was an almost perfect square, with the sides facing the cardinal points of the compass. The eastern and western sides measure each about 440 yards in length, and the northern and southern about 425 yards. On the west, north and east, it was defended by a broad and deep ditch or fosse, which in some parts is about 20 feet deep and 80 feet broad. The inner edge or escarp of this ditch was heightened into a rampart by the earth excavated out of the ditch, and, probably for some considerable time, was surmounted with wooden palisading only. On the south side, the steep slope of the hill removed the necessity for making a fosse. Later on, the inner edge of the ditch was faced as far as its upper third with a very thick and massive stone wall, 20 to 25 feet high and 10 to 12 feet thick. So that at Lincoln there is no berm, a level part of the rampart between the foot of the wall and the escarp of the ditch, in this resembling the wall and ditch at Silchester, the latter being 80 feet in width; the berm is $3\frac{1}{2}$ to 6 feet wide at Newstead, near Melrose Abbey, and more than 10 feet wide at Aldersgate, London. The reason for this arrangement is stated to be to prevent the heavy wall sliding down into the ditch, which rather confirms the view put forward, that the ditches and ramparts were some years anterior to the wall.

The lines of these fortifications are easily traced. The west wall, of which a small part still remains, began just at the junction of Drury Lane and Union Road, and ran in the line of the present earthen rampart of the castle (in which it most probably

exists), crossing Westgate and alongside the school to the north-west corner of the Waterworks Reservoir. Here it joined the north wall and ditch, which is evident at the south of Cecil Street, and a few fragments of wall still exist, just north of the east end of Chapel Lane. Crossing Bailgate, the ditch runs due eastwards, south of Church Lane, and is very well marked both in depth and breadth. A huge fragment of the wall can be seen in the field north of the East Bight. (Bight means a bend or turn and being applied to the pathway leading round just inside the walls, so we have the East Bight here and the West Bight on the west of Bailgate).

The wall has lost its stone facing on both sides and is chiefly a mass of concrete imbedding pebbles and small stones with a few courses of flat stones placed edgewise, alternately sloping to right and left like the backbone and ribs of a fish—the so-called herring-bone work, which in Roman wall construction extends right through the whole thickness of the wall, but when found—as in the castle walls—in Norman work, it only serves for a facing to the rubble within. Just at the angle of meeting of the north and east walls, where a small summer-house now stands, exists the foundation of a circular bastion of 9 feet interior diameter. From this point the east wall and ditch (the latter is comparatively perfect) run southwards on the east side of the East Bight through Mr. Shuttleworth's garden, and some parts of the wall are still to be seen therein. Crossing Eastgate, the wall proceeded southwards along the eastern side of the Deanery and the Cloisters. When the Chapter House was restored some years ago, one of the piers supporting a flying buttress was discovered to have been planted on the site of the Roman ditch, and to have had no foundations at all.

From the Cloisters the line of the wall went through the eastern transepts of the Minster to the garden of Cantilupe Chantry, where it joined the south wall on the edge of the steep cliff. This then proceeds westwards, bounding the north side of the Bishop's Palace Grounds, and forms the south wall of the Sub-deanery and Precentory gardens. Crossing Bailgate again, still running westwards, it was visible a few years ago when some new houses

in Wordsworth Street were being built, the stone face and concreted rubble interior being well shown. Thence it proceeded westwards between the Castle and Drury Lane, crossing the latter just opposite the Brewery, part of it being submerged in the Observatory Mound and joining the west wall at the south-west corner of the Castle.

In the middle of each of these walls was a gateway, of which only part of one exists. This is the one called Newport Arch in the north wall, between Bailgate and Newport. It has one large arch over the roadway and a smaller one on the east side over the footpath. (Originally there was, no doubt, another smaller arch on the west side). The large arch is 16 feet in diameter, and is constructed of twenty-six large wedge-shaped stones (of the local oolite limestone) fitted together without a keystone. The height of the arch is 22½ feet, of which about 8 feet are buried in the roadway. On either side of this arch are laid seven courses of horizontal stones, called springers, some of them 6 or 7 feet long, in order to take off the side pressure from the arch. One stone alone, just at the spring of the arch on its west side next to the wall of the white brick house, shows signs of having been moulded. On its northern face on each side is a solid buttress, about 3 feet broad by 1 to 2 feet deep, extending up the whole height of the arch. These were piers from the top of which a vaulting rib crossed from side to side. Now the arch described is in a line at least 20 feet south of the line of the north wall, so there certainly must have been an almost square tower originally, of which the part that remains is only the southern face. The gate, for example, into Herculaneum from Pompeii, had a central arched passage and two similar lateral archways, and was a double gate. At Caerwent, Monmouth, the north and south gates had each two arches, one facing the town and one facing the country. This tower then would be roofed over, and there probably was a way over from the wall on either side. Of the small side arch the diameter is 7½ feet, the height in all 15 feet, of which about 8¼ feet are still buried. The width of the whole gateway front is 22½ feet, and the total height 37½ feet.

The Eastern Gate was a little north of Eastgate, just beyond the end of East Bight. It was entire as late as 1740, having been discovered ten years previously, and was of the same dimensions, that is, 16 feet in diameter, and was constructed in the same manner, only that the arch had a keystone in the crown. The posterns were quite buried, as the ground covered all up to the spring of the arch, till about 1730 Lord Burlington had it quite opened out. Unfortunately, Sir Cecil Wray, the builder of Eastgate House, had it pulled down ten years later. Just west of this arch, in 1890, was found a strong concrete platform, on which ballistæ or large catapults probably would stand.

At the narrowest portion of Steep Hill was the first Roman Southgate, of similar character to Newport Arch, and was pulled down about 200 years ago, though "not without much difficulty," as an old Lincoln antiquary says, "as I have been informed by an eye-witness; for when the workmen, with a great deal of labour and pains, had battered one of the stones in the crown of the arch in pieces, the rest being laid without mortar, sank so equally that the arch hung as firm as ever, and their work was to begin anew." Evidently also there must have been no keystone. The wall is quite evident on the west side of the street, some 10 to 12 feet high and 3 or 4 feet thick, and just below the house on the east side can be seen the commencement of the spring of the arch, of which about the outer one-third was partially visible in 1788. Within the house adjacent still exists the eastern postern of 7 feet diameter.

The last gate to be mentioned, the Westgate, was found in 1836 (as prophecied about 100 years before) in the eastern rampart of the Castle, just north of the Sally port on its west front. Unfortunately, it collapsed under the weight of earth around it, and was either removed or covered up in fragments. The arch measured the same as Newport Arch, and was composed of about the same number of large ponderous stones, 4 feet deep from front to back, 2 feet high, and from 12 to 18 inches broad. On each side the masonry was carried up above the crown of the arch for about twelve feet, forming two pillars or wings measuring 7 feet

by 4, and between these were the remains of three smaller arches, 4 feet wide, over the centre of the great arch. The masonry on the north side was forced over by the workmen, and part of the square return wall of the gate was open to view. This showed another opening towards the north, of the same width and on the same level as those on the west front, and there were marks of timber flooring. The crown of the arch was about 19 feet below the Castle wall, about 35 feet in front of it, and the entire west front measured 36 feet. The posterns, if there were any, were not seen, if one may judge by the sketches made at the time of the discovery; the earth still stood too high to disclose them. Probably this was only the outer gateway, and if so, the inner gateway, corresponding to Newport Arch, still remains buried in the earthern mound.

At some period, subsequent to the defence and erection of the upper city, this enclosed part of Lincoln became too small for its inhabitants, or it was colonized anew, and room was made by the simple and satisfactory plan of prolonging the eastern and western walls southwards, till they came within 80 yards of the river, thus enclosing a large area, about twice the size of the original one. Part of the eastern wall still exists at its northern commencement, dividing the Bishop's Palace Grounds from the Vicars' Court; from this it went down through the Temple Gardens to the west side of Lindum Road, the ditch called the Were Dyke being very evident in the upper part of its course. Some traces of it were found in the front garden of No. 5 during some alterations a few years ago.

At the junction of Silver Street and Broadgate, probably, was a Roman gateway, from which a Roman road ran due east; later on, the gate was called Claxlide or Clasket Gate. The foundations of the wall were plainly seen when excavations were being made for the erection of the Constitutional Club at this corner. Thence, along the line of the west side of Broadgate, it ran southwards to St. Swithin's Square, there, turning westwards, it went on to the Stonebow, skirting the south side of St. Swithin's old churchyard, where pieces of it were visible some twenty-one years ago, about 7 feet thick and of good solid masonry, at a depth of about 3 feet

6 inches below the surface. This wall was also exposed when the kitchen to the east of the Stonebow, formerly the city prison, was taken down. It was even with the north front of Stonebow, and was about 5 feet thick, of unhewn stones imbedded in clay instead of in mortar, and its south face showed signs of having been repaired at various times. Also it was exposed on the west side of the Stonebow, along Guildhall Street, where it was about 15 feet high in places on its south front, the ground north of it being much higher. The Stonebow itself almost certainly stands on the site of the second south Roman Gate of the city.

From Guildhall Street the wall ran westwards along Newland to Lucy Tower Street, where it joined the prolonged western wall. A gate—Newland Gate—existed here in mediæval times, possibly on the site of a Roman one, and Newland and the street beyond to the west may also be Roman in origin. Proceeding northwards, a footway leads upwards through Beising or Besom Park, actually on the rampart of this Roman west wall, and crosses West Parade to go tolerably straight up the steep ascent of Motherby Hill. Here, also, on the western side of the footpath, the ditch is markedly in evidence. From the top of Motherby Hill the wall crossed Drury Lane and joined the original west wall at the south-west corner of the Castle. As well as the fortifications already described, there are some earthworks about 750 yards north of Newport Arch consisting of a single vallum or rampart, with a ditch in front of it, the north front being about 350 yards long, practically bisected by the Ermine Street. From each end the entrenchments run southwards towards the city for about a quarter of a mile. The eastern half of the north front is well seen in the field north of the Training College. From the rectangular character of the work, it is almost certainly Roman.

Buildings within the Walls.—Between the years 1878 and 1897, in the Bail from about 100 feet north of the turning into Westgate, on the west side of the street, was found a series of bases and parts of the shafts of a Roman Doric colonnade. Their places in the roadway are marked by stone circles, as there was no museum

whereto they could be taken, and some are on view at Mr. Allis' house. The northernmost was double, then follow four single ones, then a double one and a triple one, followed by five single ones, and another double one just where the Roman Westgate joined the Bail road. Crossing over this interval, about 15 feet wide, the footpaths, visibly much worn, on either side, was another double column followed by five single ones, and terminating in another double one. These double columns at the ends of the buildings lie east and west, the double one in the middle of the row north and south; this and its neighbour, the triple one, were probably built for support. The larger building to the north was possibly the Basilica or Hall of Justice, the smaller one may have been a temple. The diameter of the columns is 2 feet 7 inches, which would give their height when complete to be about 20 feet, making, with an entablature and probably a triangular pediment, the height of the building to be about 30 feet.

It is also probable that the Roman Forum was on the east side of Bailgate, where the County Assembly Rooms are now. A tessellated pavement of plain cubes, discovered on the site of the new St. Paul's Church, belonged to the northern building. Its north wall still partially exists, about 150 feet westwards of these columns, in a large fragment called the Mint Wall, which is about 70 feet long by 30 feet high and 3½ feet thick. It is formed of stone with triple courses of tile binding which go through the wall, about 5 feet of ashlar being between the bondings. The stones, about 9 inches thick, are hammer dressed, with wide joints and hard mortar, mixed with coarse sand and pounded brick. The stone is oolite from local quarries, one of the best and most durable layers having been chosen. The core is filled with rubble mixed with large quantities of brick. The bricks or tiles are 2 inches thick, 17 inches long, by 11 inches in width. The first course is a double one, about 2 feet above ground; about 2 feet higher, comes a triple course, and above that four similar ones, each 5 feet distant from the other.

On the eastern side of Bailgate, 27 feet from the northernmost columns first discovered, was found a row of six piers, formed of

flat tiles moulded to the shape of the pier, which was rudely cruciform with a circular half shaft to the street. These may have been for chambers for the use of clerks from the Basilica or Forum, or merely been for shops. A Doric capital was found also between the second and third pier from the north. There should be somewhere the remains of a Christian church, for we believe that there was a British Bishop of Lincoln, Adelfius, present at the Synod of Arles in 314, about 100 years before the Romans finally left the country. Numerous tessellated pavements have been found in various parts of the upper city, and two hypocausts or heating arrangements for baths. And at Canwick, about one and a half miles south-east of Lincoln, in the Greetwell fields about the same distance west, as well as at Scampton five miles north-west of the city, tessellated pavements have been found, testifying to the peaceful character of the country under the Roman rule.

Date of Buildings.—Unfortunately, there is no recorded history of the Roman conquest of the Coritani, but we may be sure that it had occurred as early as A.D. 50, when Ostorius Scapula, and A.D. 61, when Suetonius Paulinus, conducted campaigns against the Brigantes, who dwelt in the part of England afterwards known as Yorkshire, Westmoreland, Cumberland, and Durham. So that as far as the earthworks which have been described, they may be assigned to this period. In all probability we owe the other buildings and the city wall and gates to the celebrated general, Julius Agricola, who in A.D. 78, pushed northwards the power of Rome to the Grampians and the Firth of Forth. He is credited with having constructed many fortified places, which were never captured. Indeed, Tacitus expressly declares "that many states which had laid aside their animosity and had delivered hostages, were surrounded with castles and forts, disposed with so much care and judgment, that no part of Britain escaped unmolested. The succeeding winter (that is, A.D. 80) was employed in the most salutary measures. He incited the natives by private instigation and public encouragements, to erect temples, courts of justice, and dwelling houses." Newport Arch may owe its erection and its

name, Nova Porta, to Carausius, who was admiral in charge of the Channel Fleet which had its headquarters at Boulogne He revolted in A.D. 287 against Diocletian and took possession of Britain, and was acknowledged as Cæsar in two years time by Diocletian and his three fellow-emperors. As some of his coins were found in the western part of the north wall, probably he rebuilt that and the adjacent gateway. As to the garrison of Lindum Colonia, we know nothing for certain, only two tombstones have been found to soldiers of the unlucky Ninth Legion, part of which formed with the Sixth, the garrison at York. As is generally known Roman colonies were populated by veterans of the Roman Army.

Water Supply.—There have been numerous wells in the upper city, some of which, as in East Gate and the Exchequer Gate, were in use up to quite recent times. Some of these probably owed their origin to the Romans, who were eminently practical. An aqueduct, which commences at a spring about a mile away on the north side of the Nettleham Road, was certainly due to them. The water was conveyed in pipes about 1 foot 10 inches long, having no insertions, but being joined together by an outside ring, with an interceptive process of strong cement, similar to the bed in which the pipes were laid. The line of pipes led to a large well, called the Blind Well, made of brick with neat walling, its size was 18 feet in diameter at the top, narrowing towards the bottom. It was situated about 14 yards north of the Assembly Rooms in the Bail. Also between the Castle and Lucy Tower Street, just north of Brayford, was a set of conduit pipes (considered to be of Roman date) for supplying water from a neighbouring spring on the high ground.

Drainage. — Equally practical were the Romans in this department of engineering, and a well-constructed Roman sewer about 4 feet high and about 10 feet below the surface runs along the whole length of the Bail and Steep Hill, with smaller sewers leading into it from the side streets.

Roads.—The principal roads believed to have been constructed by the Romans in and about Lincoln are as follows: The Ermine Street (Via Herminia). This started from Pevensey, passed through London, St. Albans, and Godmanchester, and entered Lincolnshire at Stamford. Thence to South Witham, Easton (where it is called the High Dyke), the two Pontons, Honington, and Ancaster, Bayardsleap, Navenby, Harmston, and Waddington, descending the hill to join the Fosseway about 400 yards south of the Great Bargate —the South Gate of the city. It then runs due north through the city, and in a length of about 1,000 yards south of the crossing of the Great Northern Railway, a concreted causeway was found in four places. This was 2 feet 6 inches to 3 feet 9 inches below the surface, and the concrete, which varied from 8 inches to 5 feet in thickness, rested on made ground 2 to 9 feet thick. Close to the Witham this road had a piled foundation, which may have given rise to the name Wigford (Wicken or Wickerford).

Another piece of this road was laid bare in the High Street near Butchery Street, in 1838. This was about 3 feet beneath the street surface, and was 10 to 14 inches thick, formed or bedded on a layer of gravel 6 inches thick. Its composition was clean stone rubble, gravel, many shells and ferruginous ashes, run together with hot lime as concrete or grouting. It formed a thoroughly compact mass, and breaking it up was accomplished with much difficulty. Passing from High Street, it led up the Strait and Steep Hill through the first Roman Southgate, the Bail and Newport Arch, from which it ran northwards in an almost perfectly straight line to the Humber (ad Abum). The road is broad, rising in various parts of the course several feet above the surrounding country, and is in full use for the first seventeen miles of its course north of Lincoln.

A branch road, called Till-bridge Lane, leaves the Ermine Street on the west side, about four miles from the city, and runs straight to the Trent, the ford at Segelocum, or Agelocum—now Littleborough-on-Trent. Probably this road was designedly planned so as to escape the swampy ground lying to the west of Lincoln. Another important Roman road, the Fosseway, started from

Axminster and ran by Bath, Cirencester, Leicester, and Newark. Hence, passing through the station of Crocolana (now Brough), it runs directly north-east to Lincoln, crossing the Witham at a ford at Bracebridge, and then joins the Ermine Street just before it enters the city at Bargate. Stukeley described some of the pavement of this road before its junction, as consisting of flagstones set sideways. This road is occasionally elevated above the country through which it passes, and is in full use from Lincoln to Newark. From the site of the Roman Eastgate, a Roman road runs north-eastwards to Banovallum (Horncastle), and is fairly straight for the first eight or nine miles. In 1902, part of this was uncovered in the old Lindum cricket ground, north of St. Giles' Hospital, where the modern road bends south-eastwards at about 10 yards distance. It only consisted of two layers of stones, instead of the customary six, so it was probably only hurriedly constructed. From the same gate also, a Roman road, also called fosseway, runs perfectly straight for more than a mile to Nettleham, the Salter's Way, and the sea-coast. At the same angle of emergence as the last, a Roman road went from the site of the Roman Westgate to Burton, and Kirton Lindsey. Most likely the first mile of each of these roads was made straight for military reasons. The character of these roads, like huge railway embankments or great ramparts, is alluded to by Horace when he speaks of Æneas as one who "liberum munivit iter," on which Mr. T. E. Page quotes the frequent use of ramper—rampart—for these very roads in Lincolnshire at the present day.

Waterways.—The Fossedyke, a canal which joins the Witham at Lincoln to the Trent at Torksey, is almost certainly of Roman construction, and probably the first few miles of the Witham itself east of Lincoln was canalized by the Romans. Another dyke, or canal of similar origin, was the Sincil Dyke. This leaves the Witham about three-quarters of a mile below Bracebridge, runs due east across the main road at Bargate, and then turns northward to run parallel to the High Street as far as the present Great Northern Station, where it again went eastwards as far as the present lock at

Stamp End, when it originally joined the Witham below Lincoln. Two other Dykes, the Great and Little Gowts, which run transversely across the High Street, were probably Roman also. The intention most likely of these three dykes was to take off any overflow of the upper Witham, and so save the causeway from Bargate to the High Bridge from being flooded. The Cardyke (car or carr = fen) reaches for fifty-seven miles from close to Washingborough, three miles below Lincoln to the River Nene. It, like all the dykes except the Fossedyke, was not navigable, but served us as a catchwater drain to intercept the water coming from the higher ground to the west and so prevent it flooding the fens on the east. It is still useful as a land-drain in several portions of its course.

The President, in moving a vote of thanks to Colonel Mansel Sympson for his most interesting Lecture, said it was quite evident that in the old days the Romans carried out large engineering works in and around Lincoln, but of a military or civil engineering nature; the mechanical engineer had not appeared upon the scene at that time. He asked the members to accord a hearty vote of thanks to Colonel Sympson for his very interesting lecture.

The resolution of thanks was carried by acclamation.

Lieut.-Col. E. Mansel Sympson, in reply, thanked the President for the very kind words he had used. It was always, he said, a great pleasure to him to say anything about Lincoln, in which he had lived all his life, and which he loved devotedly. He considered it a very great honour to have been asked to give the introductory lecture, or what might be called the *hors d'œuvre*, to the more solid fare of which the members were about to partake.

RECENT EXCAVATOR PRACTICE.

By F. H. LIVENS and W. BARNES, of Lincoln, *Members.*

Much progress has been made with the steam-excavator, commonly known as the steam-navvy, since the last Meeting of this Institution at Lincoln, in 1885, when a Paper was read on the "Dunbar and Ruston Steam Navvy."

Up to a comparatively recent date, contractors had practically a monopoly in the use of these machines for public works such as railways, canals, and docks, but now more excavators are used in open mines and quarries, in more or less permanent situations, than for contract work. The change is due partly to the difficulties of the quarry owner as regards labour and the necessity for keeping costs down under present-day competition, but also to the introduction of machines more applicable to his special working conditions.

It is the purpose of this Paper to illustrate and describe some of the most interesting machines introduced within the last eight or ten years. No amount of descriptive matter can, however, give as good an idea of the possibilities of these machines as labour-savers

and of the ease and speed with which they can be handled, as the inspection of them in actual work. This not being practicable for many of the members, the Authors propose to show lantern and cinema camera pictures of their operation.

The original steam-navvy, which was capable of swinging or slewing its excavating gear through a little more than half a circle, has been now displaced to a large extent by the full circle machine, commonly known as the steam-crane navvy, and developments of this latter type are what the quarry owner and general user find so useful for their work.

The size of machine most suitable for various workings is governed chiefly by :—

(*a*) The nature of the material, and

(*b*) The output required per day.

The former will determine the minimum cutting effort to be used. For example :—

4 to 6 tons is suitable for material up to clay of medium hardness.

8 to 10 tons is suitable for stiff clay.

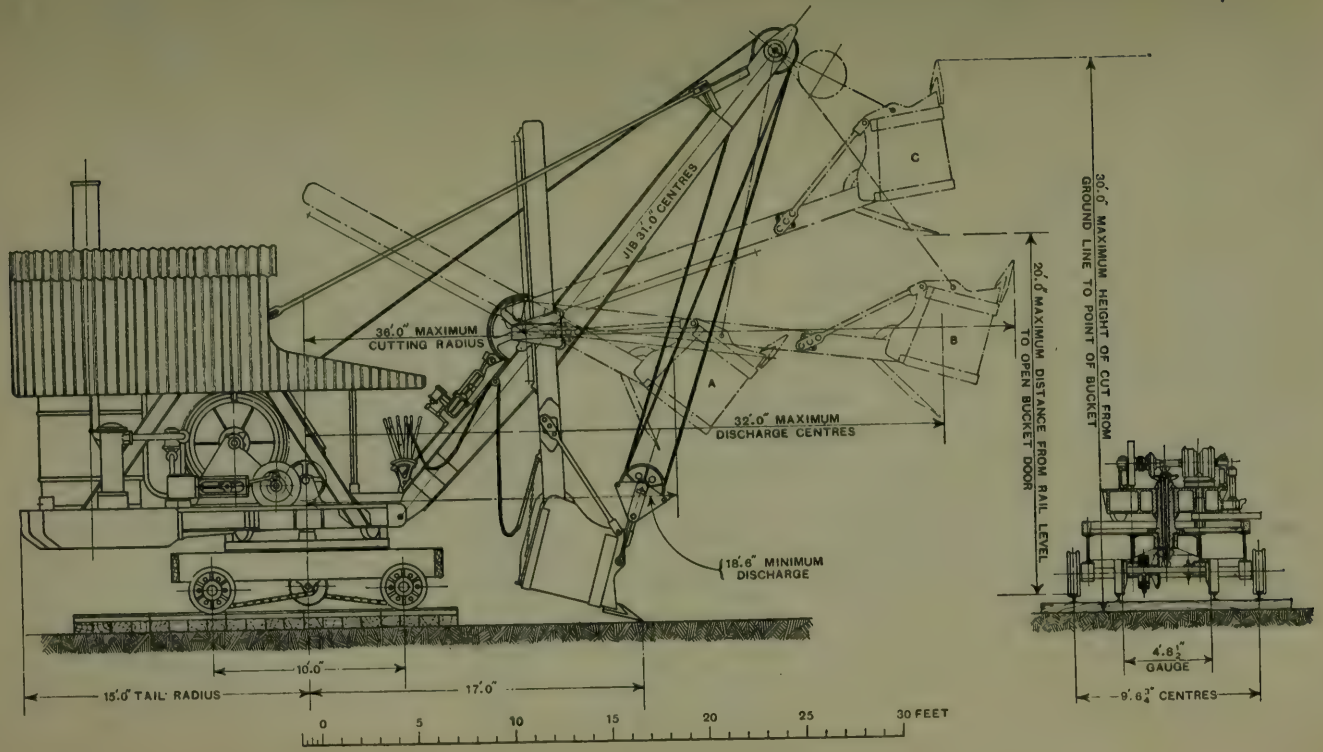
12 to 20 tons is suitable for boulder clay.

20 to 30 tons is suitable for heavier material, such as limestone and heavy iron-ore.

The output depends also upon the size of the bucket, which again is governed by the nature of the material to be excavated; thus a machine having 6 tons cutting effort is most efficient when fitted with a bucket of $\frac{3}{4}$ to 1 cubic yard capacity; if 12 tons, then the bucket should hold from $1\frac{1}{2}$ to 2 cubic yards; and if 20 tons, from $2\frac{1}{2}$ to $3\frac{1}{2}$ cubic yards, to give approximate examples.

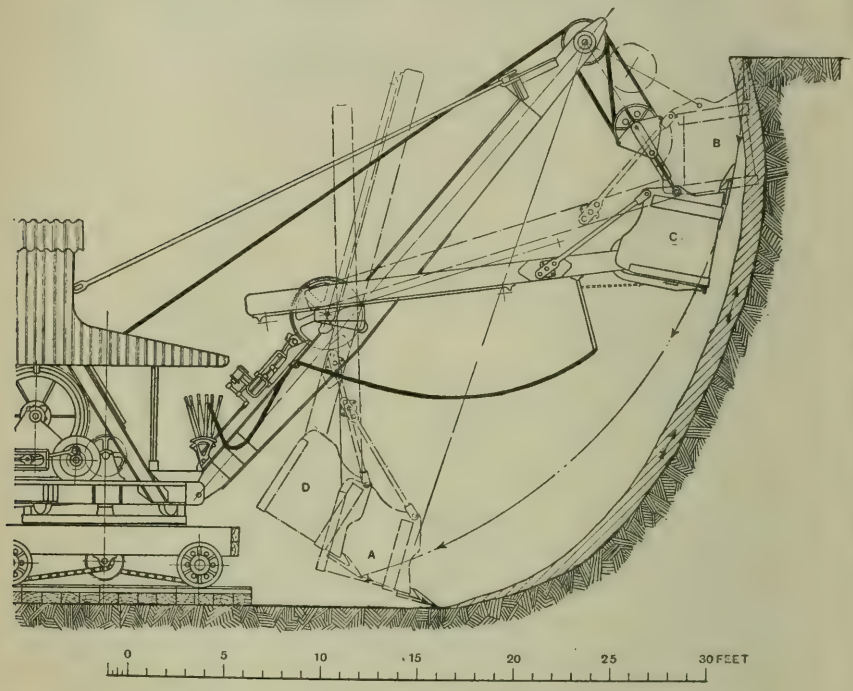
The machine in Fig. 1 and Fig. 2, Plate 2, is the type and size of machine in most general use, and is also interesting from the modifications which can be made in it to meet various conditions of working. Its weight is 55 tons net or 62 tons in working order. With the length of jib shown, the machine has sufficient stability for 20 tons cutting effort on the bucket teeth, or, if used as a crane, it will lift a load of 20 tons.

FIG. 1.—*Typical General Purpose Crane-Navvy, total weight 55 tons.*
(See photo, Fig. 2. Plate 2.)



It is supplied with a bucket of $2\frac{3}{4}$ or $3\frac{1}{2}$ cubic yards capacity, having a renewable mild steel lip-plate carrying steel teeth with renewable points of manganese steel. The main frame has the travelling gear on the underside, whilst the top face or platform

FIG. 3.—*Diagram illustrating the Cutting Action of the Bucket.*



carries a combined gear-ring and roller path, upon which the whole upper structure and excavating gear revolves. Two sets of travelling wheels are fitted, one set to standard gauge, usually 4 feet $8\frac{1}{2}$ inches, for use in moving the machine any considerable distance on a railway track; the other, a broad gauge set to carry the machine when excavating. Rollers on the underside of the bed-plate support it upon the roller path on the main frame, whilst on it are mounted the necessary engines and gearing for digging, slewing, and travelling.

The front portion of the bed-plate carries the excavating gear, comprising the jib, bucket-arm, and bucket.

The bucket-arm is fitted with long racks gearing into pinions driven from a set of small, self-contained engines fixed on the jib, which vary the cutting or discharging radius of the bucket, the bucket-arm being racked in or out as desired.

The digging motion is operated by a wire-rope on a hoisting drum of a more or less conventional type driven through a friction-clutch, actuated by a steam-cylinder for easy and quick operating. The drum is loose upon the drum-shaft and, when free of the clutch, is under the driver's control by means of a foot-brake.

The slewing motion is either driven from the main engines used for hoisting, through a set of reversing friction-clutches and the usual gearing, terminating in the gear-ring on the main frame, or in some machines by a separate set of engines which is a duplicate of those on the jib.

The travelling motion is taken off the main engines through a train of gearing connected to bevel gears at the top of the centre post, the power being transmitted from these by a vertical shaft through the centre post to the gearing under the main frame.

The complete cycle of operation is as follows :—

At the commencement, the bucket hangs in a more or less vertical position, with the teeth resting upon the ground immediately opposite the " face " of the material to be removed (shown in position A, Fig. 3). The driver starts up the engines, and throws in the hoisting clutch. The bucket is then dragged forward and upward into the face, and at the same time thrust out by means of the racks along the bucket-arms until the required depth of cut is obtained, the action being almost like putting the feed on a machine-tool. With one hand on the control-lever of the main engines and the other on the control-lever of the racking engines, the driver regulates the motion of the bucket as it is hoisted upwards towards the jib-head, the path of cut being an arc struck from the suspension point of the bucket-arm upon the jib. By operating the hoisting and racking motions together, the driver can so control the depth of cut that, providing the material is of a uniform nature, an equal

thickness of cut can be taken from the bottom to the top, and the bucket can be filled completely as the top of the cut is reached, as shown in position B. He then throws out the hoisting clutch, racks in the bucket clear of the working face to position C, and holds the bucket up on the free drum by means of his brake. As soon as the bucket is clear of the face, the slewing motion is started up and the bucket is swung round over the wagon or dumping-point. When he has reached the right position for dumping, he pulls a cord by his side which withdraws a catch on the bucket-door, and the excavated contents of the bucket are discharged. The slewing motion is then reversed, and the bucket is swung back towards the point in the face where the next cut is to be taken. By means of the foot-brake the bucket is then lowered to position D for the following cut, and a similar sequence of operations follows. The operations seem lengthy to describe, but the whole cycle can be performed in from 20 to 60 seconds, depending upon the size of the machine, but chiefly upon the length of the jib. In the navvy described, a cycle of operations takes from 25 to 35 seconds.

The machine is capable of dealing with from :—

120 to 150 cubic yards of ordinary soil or light clay per hour.
100 to 120 cubic yards of stiff clay per hour.
60 to 100 cubic yards of ironstone per hour.
60 to 80 cubic yards of loose limestone per hour.

The following is a fair average of the working costs per cubic yard loaded into wagons :—

	s.	*d.*	
One driver	2	0	per hour
One cranesman	1	3	,, ,,
One fireman	1	0	,, ,,
Four men around the machine	5	0	,, ,,
3 to 4 cwts. of coal	5	6	,, ,,
Oil and stores		9	,, ,,
Total	15	6	,, ,,

This represents a cost of approximately $1\frac{1}{2}d.$ per cubic yard for the maximum output of easy material and $3d$ for the heavy material.

Fig. 1 (page 611) shows various positions of the bucket. A is the position of the bucket when it is racked in to the minimum discharging point ; B is the extreme cutting and discharging radius, whilst C shows the highest point to which the bucket can be hoisted ; this indicates the depth of cut which can be taken without undercutting the material. It is evident that there are certain conditions of working which are beyond the possibilities of B and C on the standard machine, but these can be met by increasing the lengths of the jib and bucket-arm, and correspondingly decreasing the cutting effort and the size of the bucket.

The depth of cut should preferably not be greater than the height the bucket-teeth can reach. Anything above this has either to be blown down by explosives, broken down by hand labour, or allowed to take its chance of falling after it has been undercut by the machine. The first and second involve expense coupled with some difficulty and risk, whilst the last may be dangerous to the men working around or to the machine itself.

To cope with extra depth, the machine shown in Fig. 4, Plate 2, is provided with a much longer jib and bucket-arm to enable it to excavate a face 40 feet deep without undercutting. The "A" framing supporting the jib has been increased in height to reduce the stresses in the jib and jib-ties, but otherwise the machine is similar to the one illustrated and described under Figs. 1 and 2.

Another interesting modification is the combined steam-navvy and grab, shown in Fig. 5, Plate 2. It is a dual-purpose machine, and was designed and built to work in an ironstone quarry from which the amount of ironstone required was only sufficient to keep a steam-navvy employed rather less than half its time. Overlaying the ironstone was about 8 feet of material which had to be taken off before the ironstone could be excavated, and the proposition was that the same machine might be used to remove the cover or overburden and to dig the ironstone.

The jib of the steam-navvy was therefore extended and fitted with a grab to enable it not only to have enough reach to lay bare a sufficient quantity of ironstone, but to discharge the overburden on to the ground from which the ironstone had been removed.

Two hoisting drums are fitted to the main drum-shaft, one for use with the steam-navvy bucket, and the other for use with the grab. The same hoisting clutch and brake are common to both drums, and they are so arranged that either of the drums can be connected or disconnected at will. When the grab is required to remove the cover, the bucket is fastened back to the underside of the jib and the grabbing drum is connected to the hoisting clutch and brake. After sufficient cover has been removed, as much, in fact, as the machine can reach, the grab is disconnected and the steam-navvy drum is engaged. The machine then works as a standard steam-navvy and can dig the stone which the grab has uncovered.

Another useful modification is the machine shown in Fig. 6, Plate 2, which has an extended jib and bucket-arm to enable the excavated material to be discharged 60 feet from the centre of the machine as compared with the 32 feet of the standard machine shown in Fig. 1 (page 611).

This was specially designed for open-worked quarries in which the overburden had to be dumped from the bucket, back on to the ground from which the mineral had been removed. The machine stands upon the mineral, which in the illustration is ironstone, and will excavate ordinary soil or clay at the rate of 25 to 50 cubic yards per hour.

It is obvious that when the jib is lengthened to the extent described, the cutting effort upon the teeth must be considerably less than in the standard navvy, otherwise the machine will not be stable. The bucket must also be diminished correspondingly in size. Consequently the cutting power is reduced in this instance to 7 tons and the bucket has a capacity of $1\frac{1}{4}$ cubic yards.

The discharging radius also governs the depth of cover the machine can deal with. This particular machine, with its 60 feet discharging centres, will deal with from 15 feet to 20 feet of cover. If it were required to remove a greater depth than this, a machine with a still longer reach must be used, and if heavier cover than that indicated has to be dealt with, or in larger quantities, a more powerful machine with a larger bucket must be employed. Very large machines of this type are now in operation, weighing upwards of

300 tons in working order, and carrying buckets of 7 cubic yards capacity, capable of dealing with 200 to 300 cubic yards of material per hour. Such machines have a discharging radius of 100 feet. They are naturally slower in working than lighter machines, the time taken to make a complete cycle of operations being from 50 to 65 seconds.

An alternative to the long jib-crane navvy for removing and dumping quarry overburden direct, is an excavator with a normal length of jib, working in conjunction with a transporter, for taking away the excavated material and dumping it, as shown in Fig. 7, Plate 3. The navvy itself is exactly similar to the one described in connexion with Figs. 1 and 2, and stands upon mineral.

The transporter travels in the bottom of the quarry and consists of an underframe and tower, supporting a double cantilever track for the wagon or skip. This underframe is fitted with the necessary wheels and travelling gear which enable it to be moved about the quarry under its own power, and on the underframe are the boiler and winding engines for actuating the transporting gear, which are sufficiently large to haul a fully loaded skip up the inclined track at a speed to suit the excavator, and, in addition, supplying the power for travelling. The skip is about 25 per cent larger than the excavator bucket to avoid spillage. It is fitted with a hinged door similar in principle to the bucket of the digger, but arranged so that it can be opened at any desired point along the transporter track by means of a movable tripping jack, which is traversed by a small hand-winch on the transporter, within easy reach of the driver.

The operations are as follows :—

The excavator takes a cut and discharges the material into the skip standing at the bottom of the track. The transporter engines, controlled by the transporter driver, then haul the loaded skip up the track to the tipping point, where the catch holding the door in place is automatically knocked out, and the contents are discharged. The driver throws out the hoisting clutch and lowers the skip on a free drum under the control of a brake.

The adjustable tripping-jack is a useful feature of the machine

as the dumping point can be varied so as to leave the surface of the dump approximately level.

The transporter wagon makes a round trip in 25 seconds, which is several seconds quicker than the average cycle of operations on the excavator, so as to avoid the latter having to wait for the transporter. It really follows the axiom of the ideal contractor, who should arrange his wagon service so that his steam-navvy never waits for empties.

An output of 80 to 120 cubic yards of ordinary material can be obtained per hour. Compared with a long jib-crane navvy of equal bucket capacity, the plant is capable of a larger output, because of the obviously quicker working speed of the machine with the shorter jib, which reduces the slewing time, and consequently the period taken in making a complete cycle of operations; in other words, the function of the long jib is transferred to a separate machine, the transporter, in which a still longer reach can be obtained.

The coal consumption of the two separate machines is also rather less than that of the single machine with equal bucket capacity, as more power is required to slew the latter, because of its increased weight, due to the long jib and the weight required to balance it.

The disadvantages are the extra man employed as driver of the transporter, and the necessity of moving and laying a track for two machines instead of one.

The comparative weights are as follows :—

A machine with a normal length of jib and a bucket capacity of $2\frac{1}{2}$ to 3 cubic yards weighs 55 tons net, whilst with the transporter the weight is 105 tons. A long jib excavator with the same size bucket and dumping radius of 80 feet weighs 150 tons.

An endless carrying belt is occasionally used in place of the skip, fed from a revolving pan at the foot of the transporter, into which the excavator discharges. The advantage of this arrangement is its lighter weight compared with the track for the skip on account of the distributed load on the belt, as against the concentrated load of the skip. Its disadvantages are the greater maintenance charges—chiefly belt renewals—and the fact that the discharge takes place at one point—the end of the belt. If the ground has not to be left

level again, but can remain in the ridge formation caused by the discharge from the belt-conveyor, the latter point does not count, but as generally the land has to be put back into cultivation, much additional expenditure is incurred if the levelling has to be done by hand.

It is obvious that one ideal would be a simple machine which would combine, if possible, the advantages of the two separate machines, by possessing the quick working of the short jib and at the same time have the long reach of the transporter for dumping the overburden. These conditions are embodied in the combined excavator and transporter shown in Fig. 8, Plate 3.

The machine is a single-bucket excavator carrying a wagon transporter supported by a common tower and main frame, and weighs about 85 tons. The method of discharging the material into the wagon is its most novel feature, as, instead of the bucket being swung round over the wagon in the usual way, the hoisting is continued after the cut is finished, until the bucket is pulled right into the jib and immediately over the top of a chute fitted between the sides of the jib.

Just as the bucket is coming over the mouth of the chute, the catch holding the door in place is mechanically pulled off, the door falls and the contents of the bucket are discharged down the chute into the wagon standing on the transporter track at the foot of the chute.

The excavating gear only swings through a little more than half a circle, and the bottom centre of the chute coincides with the slewing centre of the machine, so that the wagon, when lowered down as far as it will go, is also immediately over the slewing centre, and is therefore always correctly placed, irrespective of the position of the jib.

The underframe of the machine is triangular in plan and is fitted with three bogies, one at the front immediately under the slewing centre, the other two at each end of the underframe at the dumping side. The platform of the underframe supports the tower and carries the boiler, transporter engines, and a separate set of self-contained engines for slewing. The main hoisting or digging engines are

mounted upon an upper storey of the tower and above the track of the transporter. The bucket has a capacity of 2 cubic yards. Two men are sufficient to operate the various motions, one the driver of the transporter engines, who also attends to the firing of the boiler, and another who controls the excavating mechanism.

The machine can complete a cycle of operations in 20 seconds, and is capable of an output of 60 to 80 cubic yards of heavy clay per hour.

When the material is light and easy to dig, the endless-bucket type of excavator, feeding on to a belt-conveyor, may be a very useful and efficient combination, as shown in Fig. 9, Plate 3. This shows a machine which is the largest of its kind and is operated electrically by a three-phase current. It is capable of an output of 80 to 150 cubic yards per hour, and was designed to remove 50 feet of overburden consisting of sand, peat, and gravel. The bucket ladder is approximately 100 feet long, and the conveyor 130 feet long.

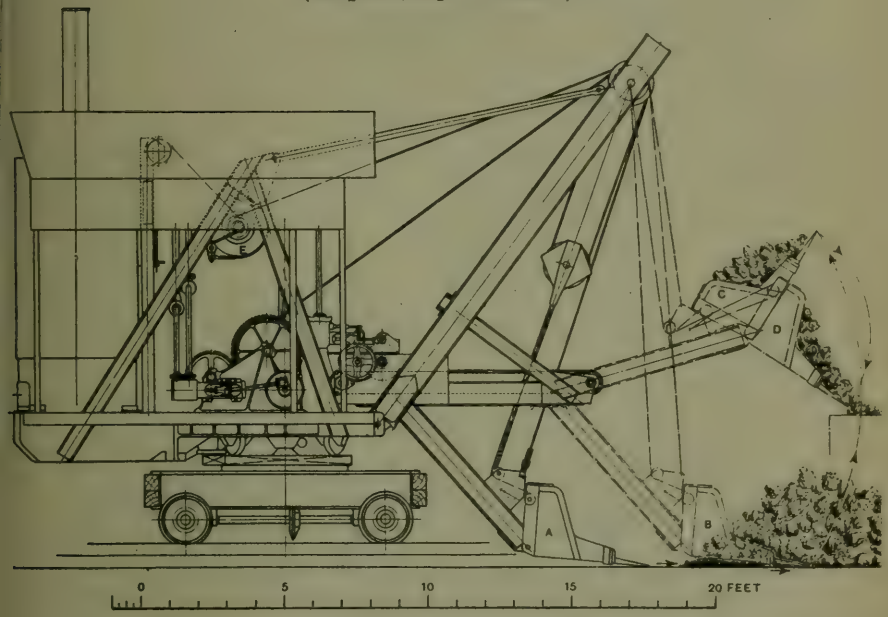
One result of the present-day labour situation is the demand for a small machine, due not only to the high wages which have to be paid, but to the increasing disinclination of men to work with pick and shovel. Previous to the War, hand labour was so cheap, that for small outputs there was little margin to cover the charges incident to the use of machinery; therefore comparatively few excavators below 30 tons in weight and 8 tons cutting effort on the teeth were used in this country. Labour conditions have now so altered, however, that brick manufacturers, quarry owners and small contractors must have something more economical than hand work, and a machine of the size and type shown in Fig. 10, Plate 4, meets their requirements.

In general design and working the machine is similar to the larger machine previously described, but it only weighs about 16 tons net, and carries a bucket of $\frac{5}{8}$ of a cubic yard capacity, with 5 tons cutting effort upon the teeth.

It will deal with any class of material up to fairly stiff clay, in quantities up to 50 cubic yards per hour; in fact, in many places, such as brickworks, an output of 6 to 7 cubic yards per hour may be all that is required, and quite a number of machines

are replacing hand labour even for this small output. For the maximum output, two men upon the machine and two or three around can be usefully employed, but for small outputs one man upon the machine and one or two around it are sufficient. Flanged wheels for working on rails are generally preferred, but self-laying tracks do away with the need for one or two of the attendant men,

FIG. 11.—*General Arrangement of Coke Loader.*
(See photo, Fig. 12, Plate 4.)



and are finding increasing favour, although adding about 30 per cent to the price. Road wheels are also sometimes used in place of the rail wheels or self-laying tracks, but unless the surface of the ground is quite hard, like that of a macadam road, timbers are necessary under the wheels to prevent them from sinking in when the machine is excavating and when travelling over soft ground. As the timbers are easily damaged by the wheels and costly to renew, flanged wheels or self-laying tracks are more economical.

A modification of this small machine is shown in Fig. 11

(page 621) and Fig. 12, Plate 4, for loading coke from a level coke-oven bench. Instead of being fitted with the usual steam-navvy bucket, it carries a large fork 4 feet 6 inches wide, arranged with tines similar to a hand fork. The racking motion for regulating the stroke of the bucket-arm is also differently arranged, as, instead of the point of suspension being fixed and the working length of the arm varied, as in the case of the steam-navvies previously described, the length or working radius of the arm is fixed, and the suspension point is racked in or out horizontally. This enables the fork to be thrust along the bench underneath the coke so as to avoid breaking it.

Two independent wire-ropes similar to those used in connexion with double rope grabs, pass over the jib-head; one of them is connected up to the hoisting drum, the other coils and uncoils on a free drum, and is used for holding up the fork independently of the main rope, when it is required to discharge the coke from the fork. The free drum is rotated in one direction by the lowering of the fork, and in the reverse way by a falling weight in order to keep the rope taut.

The method of working is as follows :—

The arm of the fork is racked in towards the machine as far as it will go, and the fork is lowered on to the coke bench (*see* position A, Fig. 11). The horizontal racking gear is then put into operation, and the fork is thrust under the coke until it is filled (*see* position B). The hoisting drum then comes into use, and the fork full of coke is lifted out of the heap (position C) and swung over the wagon standing alongside the coke bench.

To discharge the coke from the fork, the brake on the free drum E is applied, and the main brake released. This allows the fork to tilt downwards and to discharge its contents, as shown in position D.

At the opposite end of the scale to the small crane-navvy described, is one shown in Fig. 13, Plate 4, which has 30 tons cutting effort on the teeth and weighs about 120 tons net. It is shown excavating a face of 27 feet in depth, composed of very thick beds of ironstone, some being over 3 feet thick, which necessitate the use of explosives to loosen them.

Inner wheels for the standard gauges are not fitted because of the great weight of the machine. Instead of these, the outer wheels

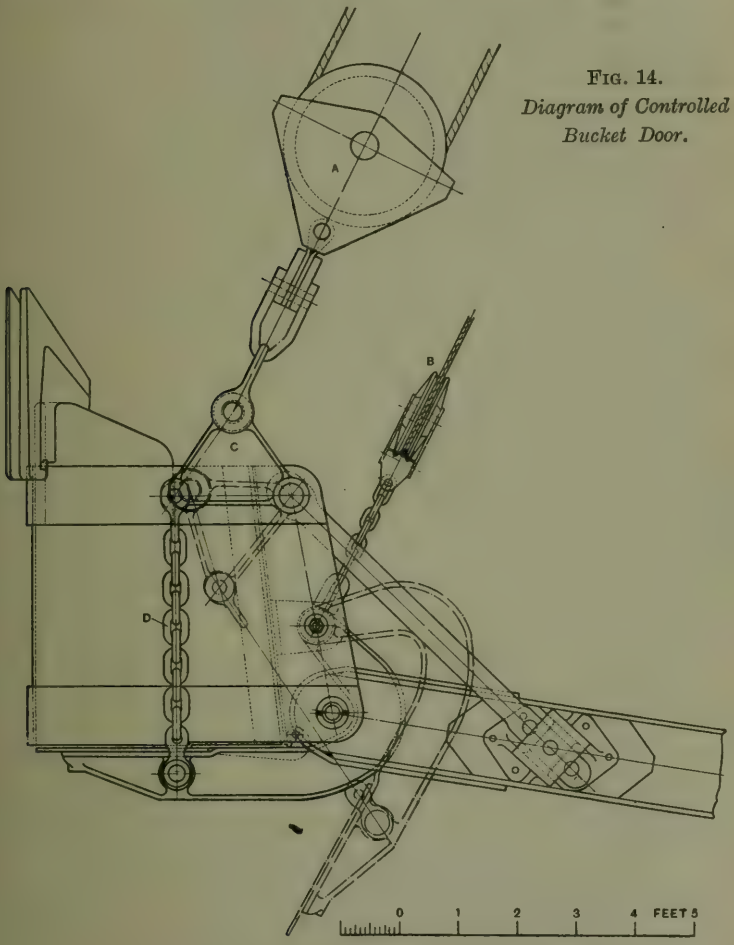


FIG. 14.
Diagram of Controlled Bucket Door.

have twin treads to enable two rails to be used under each wheel, placed alongside each other, about $6\frac{1}{2}$ inches apart. Mild steel side girders are bolted to each side of the upper bed-plate and are extended to the rear of the machine to carry the boiler, water-tank

and ballast box. The boiler is one of the loco-multitubular type, as the steam supply required is beyond what is practicable for the vertical pattern.

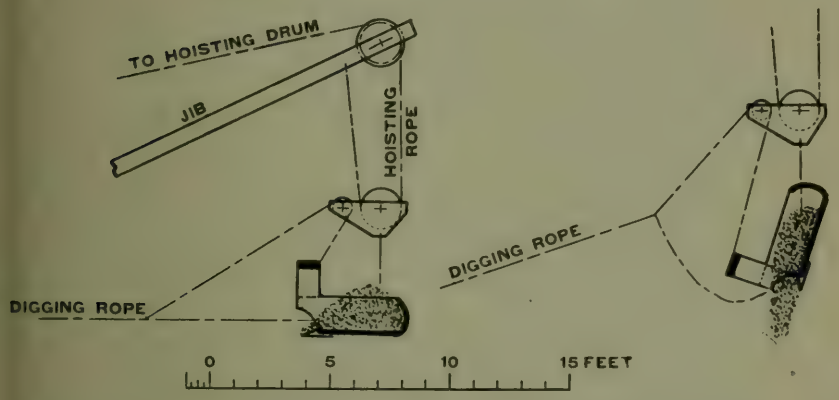
Three sets of double-cylinder engines are fitted to the machine; the largest has cylinders 10 inches by 14 inches, and is used for hoisting, whilst two sets have 9 inch by 9 inch cylinders, one on the bed-plate for slewing and travelling, and the other mounted on the jib for racking. The bucket has a capacity of 4 cubic yards, and is fitted with a controlled door by means of which the rate of discharge can be regulated. This is done by two sets of wire-ropes (*see* Fig. 14) passing over the jib-head, one, set A, for use in hoisting or digging, the other, set B, for holding up the bucket in a similar manner to that described for the coke-loader.

The hoisting-rope, instead of being connected directly to the bucket, is fixed by means of the bale to two triangular rocking castings C, and these in turn are connected by chains D, which pass down each side of the bucket to a cross-bar fitted to the back of the door. No catch is used on the door, as it is held closed by the pull on the cross-bar from the hoisting rope. When it is desired to discharge the excavated material, the bucket-arm and bucket are held by means of the holding-up rope, and the hoisting rope is lowered out. On a standard bucket fitted with catch-gear and one set of hoisting ropes, the effect of lowering the hoisting rope would be to lower the bucket, but in this case the bucket is held and the door only is lowered under the control of the brake on the hoisting drum. Ordinary catch-gear may be used, but then the door opens quickly to the full extent and dumps the full load into the wagon. This does not matter when the wagons are specially constructed, but when standard railway companies' wagons or light wagons, as used for hand labour, are used, the effect of dumping 4 tons of ironstone from a height of 4 feet to 6 feet is bad for the wagons. The brake gear described above, however, enables the door to be opened gradually and the rate of discharge to be controlled to any extent. In fact, it is possible to discharge a portion of the load into one wagon, close the door again by hoisting, and dump the remainder of the contents into another wagon. A complete cycle of operations

can be made in from 30 to 35 seconds, and it will excavate and load between 250 and 400 tons of ironstone in an hour, with two men on the machine and four or five round it; or comparing it with hand labour, as one man can excavate and load about one ton per hour, the machine is capable of replacing 200 to 300 men if a wagon service can be organized to deal with its maximum hourly capacity.

The single-bucket excavators previously described have three characteristics, they excavate *above* the level on which they stand,

FIG. 16.—*Diagram of Dragline Bucket.*



they dig away from the machine, and they *advance into* the excavation as it proceeds. The machine shown in Fig. 15, Plate 4, works in an exactly opposite manner, as it excavates *below* the level on which it stands, it excavates *towards* itself, and travels *backwards* when it has excavated all the material within reach.

It is known as a dragline, because the bucket is dragged towards the machine on a flexible rope instead of being guided by a radial arm.

It is very useful for drainage work and for situations where the ground is too wet for a machine to stand in the bottom. In construction it is similar in many respects to a crane-navvy, in fact, the latter may be designed so that, by adding an additional drum to the hoisting engines and fitting a longer jib and special bucket, the machine can be converted into a dragline.

The main frame carries the usual travelling gear, which may either be flanged wheels or endless tracks. The upper bed-plate carries the hoisting engine and either a separate engine for slewing, or reversing friction clutches driven from the main engines. The hoisting engine is fitted with two drums ; one is for digging, the other for lifting the bucket out of the excavation, regulating the depth of cut, and allowing the bucket to swing back for discharging and for another cut. The digging rope, instead of passing over the jib head, as on the crane-navvies, passes out at the front of the machine close to the foot of the jib, and is connected to the bucket bale. The lifting or hoisting rope has only to take the weight of the bucket and its contents, and is carried over the head of the jib and attached to the body of the bucket. The jib is of the lattice pattern, much lighter in construction than that of a crane-navvy, because in a crane-navvy the jib has to take practically the whole of the excavating stresses, not only on account of the digging rope passing over the jib-head, but also because the bucket-arms, with their attendant slewing and digging stresses, are connected to the jib ; the dragline jib has, however, only to take the load due to the lifting rope, together with slewing stresses. As the loading at the jib head is much less than that of a crane-navvy of equal size and weight, the jib can be made much longer, which is a great advantage for dragline work, as it enables the bucket to be thrown out further to take a deeper and wider cut. The bucket is very simply constructed, being open both at the front and the top. The digging rope is connected to a bale at the front of the bucket, Fig. 16, whilst the hoisting rope is taken to the body or back of the bucket. The contents are discharged by holding the bucket up on the hoisting rope and releasing the tension of the digging rope. This allows the bucket to tilt forward to discharge the contents from the open mouth.

A large working radius is very useful in this machine, and as working height above the rail is not needed, excepting for dumping, the jib has a much flatter angle than in a crane-navvy, and in addition is usually fitted with derricking gear for altering the working radius. The angle of the jib varies from 25° to 40° from the

horizontal in the case of a dragline, and from 45° to 60° for a crane-navvy.

The method of working is as follows: The bucket is lowered out at its extreme radius to the foot of the excavation, the digging drum is put into gear and the bucket is dragged into the material towards the machine, the thickness of the cut being regulated by means of the tension on the hoisting rope. If the cut is correct, the hoisting drum unwinds freely. A thinner cut can be taken by braking the hoisting line. When the bucket is full, the digging clutch is thrown out and the hoisting gear is put in. The bucket is then lifted on the hoisting rope and the digging rope is allowed to run out under the control of the brake so as to swing the bucket towards the front of the jib. The machine is then slewed over the dumping point and the bucket discharged. The bucket can be swung out beyond the jib-head radius to take a larger radius of cut by drawing in the empty bucket on the digging line, and then letting it run out as freely and as fast as it can, so that it swings beyond the jib-head.

The speed of operation is approximately equal to that of a crane-navvy of the same weight, the size of bucket in proportion to the cutting pressure also being similar.

It may be interesting to give some comparative working information of some of the machines illustrated and described, and for that reason some of them have been accurately timed and tabulated in the following Table (pages 628–9).

The machines seen at the visit to Scunthorpe are those shown in Figs. 1, 2, 6, 7, and 13. Excepting the machine shown in Fig. 9, all the others have been designed and constructed at Lincoln.

The Paper is illustrated by Plates 2 to 4 and 5 Figs. in the letterpress.

TABLE 1.

Net Weight and Type of Machine.	Material Excavated.	Capacity of Bucket.	Duration of timed working.	Net working time.	Time lost from:—
55 tons Crane Navvy	Ironstone fairly easy to dig	2·75 cubic yards	2 hours 2 mins.	1 hour 18 mins.	Waiting for wagons, 33 mins. Moving up, 11 mins.
55 tons Crane Navvy	Heavy Ironstone	2·75 cubic yards	1 hour 57 mins.	1 hour 22 mins.	Waiting for wagons, 29 mins. Moving up, 6 mins.
56 tons Long Jib Crane Navvy, 60 ft. discharging centre	Sand	1·50 cubic yard	1 hour 29 mins.	1 hour 7 mins.	Moving up, 22 mins.
55 tons Crane Navvy working with Transporter	Stiff clay and loam	2·75 cubic yards	2 hours 26 mins.	1 hour 47 mins.	Moving up, 39 mins.
43 tons Crane Navvy working with Transporter	Stiff clay and loam	2 cubic yards	1 hour 25 mins.	1 hour 17 mins.	Moving up, 5 mins. Waiting for skip, 3 mins.
85 tons combined Excavator and Transporter	Stiff clay and sandstone	2 cubic yards	1 hour 36 mins.	1 hour 16 mins.	Moving up, 20 mins.
120 tons Crane Navvy	Very heavy Ironstone	4 cubic yards	1 hour 40 mins.	50 mins.	Waiting for wagons, 40 mins. Changing wagons, 10 mins.

NOTE.—These are ordinary working speeds and outputs. It will be seen in col. B. Compared with these, an average man can excavate from 1 cubic

TABLE 1—*continued.*

Total no. of cycles of operation or cuts.	Average cuts per hour inclusive of time lost.	Average cuts per hour exclusive of time lost.	Total amount of material excavated.	Average quantity per cut.	Average output per hour inclusive of time lost.	Average output per hour exclusive of time lost.
					A	B
109	54	84	254 tons	2·34 tons	125 tons	196 tons
99	51	72	228 tons	2·30 tons	117 tons	167 tons
110	74	99	120 cubic yards	1·1 cubic yard	81 cubic yards	107 cubic yards
191	79	107	380 cubic yards	2 cubic yards	156 cubic yards	213 cubic yards
126	89	98	226 cubic yards	1·8 cubic yard	160 cubic yards	176 cubic yards
129	81	102	170 cubic yards	1·32 cubic yard	106 cubic yards	134 cubic yards
71	43	85	269 tons	3·8 tons	161 tons	321 tons

that the actual outputs per hour in col. A are from 50 to 85 per cent of those yard of clay or ironstone to 2 cubic yards of sand per hour.

Mr. F. H. LIVENS said it might be interesting to the members to know that, as far as he had been able to discover, the first excavator used in this country was on the Great Eastern Railway, about 1845 or 1846. The excavator consisted of a wooden frame and a wooden jib, and was now known as of the locomotive type, that is, it travelled forward on wheels, and the jib had a swing of about half a circle; it was of the same pattern as afterwards was developed in America, and he believed originated on that side. The first machine made in Lincoln was at the beginning of 1876; he believed it went to the Victoria Docks Extension, London, the excavation of which had then just begun. The second machine he saw under construction himself in March of the same year. These machines were of the same type as those described in the Paper which was read before the Institution Meeting at Lincoln in 1885.

Mr. WILLIAM BARNES then gave brief descriptions of each machine dealt with in the Paper. These were freely illustrated by lantern slides, which, in addition to the illustrations appearing in the Paper, included others showing the working movements of the excavators as described therein. About 1,200 feet of film was then projected on to the screen by means of a kinema lantern to show the excavators in actual work. Complete views of the machines were followed by near views of the bucket digging materials, varying from sand to stiff clay and ironstone. One particular film showed the 120-ton crane-navvy digging and loading 15 tons of ironstone in 1 minute 45 seconds, which was equal to the work of 400 men by hand labour alone.

Discussion.

The PRESIDENT said it was evident from the applause that had accompanied the showing of the slides and the kinema pictures that there was no necessity to pass other than a formal vote of thanks to the Authors for their most interesting contribution, which he was sure the members had enjoyed immensely. He had been particularly struck by the fact of how very much more quickly the eye could take in a subject than the ear. Personally, he felt that he had learned more in ten minutes than by two hours' reading.

The resolution of thanks was carried by acclamation.

Mr. L. A. LEGROS, O.B.E., congratulated the Authors on the very happy balance they had struck in the Paper by giving line engravings of the details of the machines, process blocks showing the actual machine at its work, and finally and best of all the introduction of the kinematograph in illustration of the subject of the Paper, because there were certain classes of machines, which dealt with the rougher side of nature, which could not be represented properly at work, even in line drawings or in process blocks. The natural difficulties of excavator work had just been made clear to the members by the views that showed the great diversity of material which had to be handled.

There was one subject which those who were not responsible for dealing with such machines might find it of interest to have explained to them, namely, whether the ironstone ground was shaken up by dynamite in places, or whether there was any other preparation made before the navvy began to work. Was the ground naturally sufficiently loose to permit of the navvy working without such preparation? Another subject to which he desired to refer was the use of the excavator for trench work. He had seen many photographs taken in America of a number of excavators designed exclusively for excavating long trenches and for excavating each side of a new railway, the spoil being thrown up to form the

(Mr. L. A. Legros.)

embankment of the railway through low-lying districts such as the fens. Perhaps that class of manufacture was not such as interested Lincoln engineers, in view of the great change that had taken place in foreign trade owing to the failure of the eastern part of Europe to place orders which had previously formed so large a part of the trade of the engineering firms of the city.

Mr. R. E. WESTWOOD said he was not a mechanical but a civil engineer, and he had been exceedingly interested in the quantities referred to in the Paper, particularly the amount of work done by the steam-navvy and the time it took to do it. As a large user of those machines, it afforded him much pleasure to confirm the figures which the Authors had set forth. He desired to associate himself with the thanks that had been accorded to the Authors and to the firm they represented, not only for the Paper that had been read but for the great amount of labour they had of recent years put into the development and the perfection of the Steam-Crane Navvy. The enormous progress that had been made from the time of the old "Tower" navvy down to the design of the No. 30 machine, which worked in a face 30 feet deep, could hardly be realized except by those who had had the actual handling of it. To Messrs Ruston and Hornsby, perhaps more than to any other firm in England, the thanks of civil engineers, who had to move large masses of earth and rock, were due. That firm had studied the requirements of civil engineers very closely; they had associated themselves with every movement for progress, and he sincerely trusted they would reap the reward that was due to them by having an increased demand for their machines; in fact, he was informed that the demands already being made upon them were greater than their vast establishment could cope with. But although the machine which had been illustrated appeared as near perfection as was possible to the mechanical engineer, he did not think the civil engineer would admit that that was so, and he did not think a progressive firm like Ruston and Hornsby, and progressive mechanical engineers like the Authors, would remain still under present conditions. Perfection had not been attained.

There was still room for progress, and he and many others, who were engaged on the same class of work, trusted that that progress would be made in their lifetime, in order that they might benefit from it. The present output from the machine was great, but they sincerely trusted that in the future it would be greater still.

One of the troubles that the user of such machines in rock, or at any rate in ironstone or any other mineral that was got by that means, encountered, was the big lumps. A No. 30 machine, working in a face 30 feet deep, tore down an enormous amount of ironstone and took to the wagon at every operation 4 cubic yards of excavated material. Lumps might be found inside that 4 yards which would break the heart of any ironmaster who had to smelt the material, and he thought the genius of the mechanical engineer should be directed to the subject of finding some means whereby the rock would be broken into smaller pieces than was at present the case, without of course making too much "small." The civil engineer required assistance in his work, but too often, perhaps, he imagined that the mechanical engineer was a miracle worker and could do everything.

There was another and still more vital matter to which he wished to refer. It was well known that surface mining, or quarrying as it might be called, whether for ironstone, coal, or any other mineral, was much cheaper than underground mining, and those who had to do surface mining for a living regarded with concern the moment when it was found that it was no longer possible to remove economically the overburden in order to get the material, and when it was necessary to go underground for it. Personally he believed that, with the assistance of mechanical engineers, the moment of diving underneath the ground would be deferred for a very long time. A few years ago surface mining engineers declared that 30 feet of overburden was about the limit that could be removed with economy, but the mechanical, prompted probably by the civil engineer, had devised such means of digging and transporting overburden that this depth was no longer considered the limit, and even 60 feet was now regarded with something not far removed from equanimity. He was at the

(Mr. R. E. Westwood.)

present time removing 40 feet and he thought that, with some further call upon the inventive genius of the mechanical engineer, 100 feet of cover would be removed before it was found necessary to go underground. The way by which he thought that this could best be done was by increasing the length of transportation, and the tower transporter working in conjunction with a steam-navvy—an illustration of which had been shown—was a step in the right direction. This illustration had shown a little truck, carrying $2\frac{1}{2}$ cubic yards of excavated material, running from the loading steam-crane navvy to dump, over a conveyor 135 feet long, making the journey out and back in 25 seconds—the speed of conveyance being somewhat greater than the loading speed of the navvy. Such a transporter, working in conjunction with an efficient navvy, dealt easily with 40 feet of overburden, and if the mechanical engineer would devise a transporter which, at reasonable cost, would carry three times as much material to three times the distance, he was of opinion that the problem of dealing with 100 feet of overburden was practically settled. He put that forward as a suggestion that was, in his opinion, well worth consideration. He had been in touch with some of the large American makers, but they would not face the problem at all. They preferred, when the dump was over 100 feet distant, to wagon the material away. Perhaps this operation was more cheaply done in America than here, but he held that a large-capacity navvy, working in conjunction with a long transporter, would be found a much cheaper proposition in dealing with deep cover than "wagoning away," which was always cumbrous and expensive.

Mr. Legros had asked whether the rock had to be shaken by explosives before it was dealt with by the excavator. In practically every case it was advantageous to do so. There were some rocks so soft that the navvy could dig them as they lay, but most iron ores were best got after a preliminary shaking up by judicious blasting.

Mr. WILLIAM H. PATCHELL (Member of Council) said that,

while listening to the Paper and looking at the illustrations that had been shown, the minds of many of the members must have gone back to Mr. Livens' old colleague, William Weatherly, whose name was so closely associated with the introduction of the steam-navvy. It was a household word with all railway contractors thirty years ago, and it would have facilitated Weatherly's work enormously if he had been able to show what the Authors had just shown the members. He thought they had had placed before them an excellent example of kinematograph work. Kinematograph films were usually run through the lantern at such high speeds that engineers and even ordinary people got vexed with them, and he thought the Authors and their operator were to be congratulated on such well-timed and beautifully taken pictures. It simply showed what a very valuable educational tool engineers possessed in the kinematograph.

The PRESIDENT said that two of the previous speakers had already referred to the great advantage of pictorial methods of presenting a subject to an audience, and he desired to ask the Authors if they would be kind enough to let the Institution have the kinematograph films for use at the Conversazione to be held on the 21st October next. He thought they would make a very interesting feature on that occasion. Mr. Westwood had, he thought, put forward many points which would provide food for thought to the Authors for some time to come, but he had no doubt they would eventually evolve a machine meeting Mr. Westwood's requirements.

Mr. F. H. LIVENS, in reply, thanked the members for the high appreciation that had been expressed of the Paper, and particularly thanked Mr. Westwood, who had made such original and pregnant remarks, which it was hoped would some day bear fruit. Mr. Westwood had already answered Mr. Legros' question as to explosives. When the members visited Scunthorpe later one of their hosts would be Mr. Westwood, and they would then have the opportunity of seeing how the ironstone was loosened. The depth

(Mr. F. H. Livens.)

and distance apart of the bore-holes which were put in and charged depended entirely upon the character of the material. In Northamptonshire the ironstone was sufficiently kind in character, so that he believed explosives were not used at all.

With regard to the point raised by Mr. Westwood as to the economical limit of surface mining compared with underground mining, and extending the surface mining limit by the use of still larger machines, he thought all the members would realize that Mr. Westwood had suggested a very big problem, because, as the size of the machine and the length of the transporter were increased, the weights increased in greater ratio, and it was necessary also to increase the tracks which carried them. He very much feared that the enhanced cost would cut heavily into the economy which the larger machines should realize. There was another point also with regard to very heavy machines which applied particularly when they were delivering into wagons, namely, that the service had to be very perfect in order that there should not be waste of time. In Table 1 (pages 628–9) there could be seen the percentages of useful time to total time, and it would be noticed that they varied, roughly speaking, from 50 per cent up to 90 per cent. The Authors would not forget Mr. Westwood's remarks, and he might rest assured that they would do what they could to meet his requirements.

Mr. Legros had asked whether the machine had been used for digging a trench for a pipe-line. His company had made one such machine which was sent to South America. It cut about 22 miles of trench for a pipe for waterworks not far from Monte Video. A very capable man was sent out in charge of the machine and carried through the contract. The ground proved much more difficult in places than what had been expected; some of the stuff did not lend itself to easy cutting, but still the work was completed successfully. There could be no doubt that there were other uses for mechanical excavators outside those which had been referred to in the Paper, but, like all other engineers, his firm had been obliged to concentrate on certain patterns so as to make them to the very best advantage in greater quantity.

Mr. WILLIAM BARNES, in reply, said one point had been referred to by Mr. Westwood which Mr. Livens had not dealt with in his reply, namely, the large-sized ironstone excavated by the navvies. That was no doubt a very serious disadvantage to a blast-furnace manager, but he thought the time was coming when large crushers would be used in connexion with the steam-navvies. They would not worry about the large pieces; the material would be taken direct to the crushing plant and crushed to a suitable size for the blast-furnace. He believed that if the ironstone were crushed to a small uniform size before being put into the furnace, the less fuel it consumed and the more easily it melted, and he hoped improvements would be made in that direction. He desired to assure Mr. Westwood that his firm would do all they could to meet his requirements. They had kept on increasing the size of the machines. They started with a machine weighing 32 tons, and the latest pattern weighed 120 tons, and they were still growing. The question that had to be borne in mind was what demand there was for such a large machine. The larger a machine was, the more expensive it became, not only on the capital outlay, but on interest and depreciation of capital, and the point had to be decided whether that expense was justified. Personally he thought it would be. A few years ago it was thought that about 20 feet of cover was the least that could be taken off as an economic paying proposition with an excavator, whereas the economic depth of working had now been got down to 5 or 6 feet. A few years ago the deepest cover that could be taken off with any steam-navvy was 25 or 26 feet, but they had now reached 40 feet, and he thought before long 50 feet would be attained.

ROAD TRANSPORT BY STEAM-VEHICLES.

By P. W. ROBSON, O.B.E., of Lincoln.

1. *The Permanent Functions of Road Transport.*—It may be stated as an axiom that the methods of transport of goods have recently undergone permanent changes of a far-reaching character. Shorter working hours and diminished output of work per man have introduced a disturbing factor in the handling of goods traffic on railways which demands a fundamental remedy. That remedy will doubtless be of a many-sided character, involving those larger and changed types of railway trucks, and those different methods of railway working about which one has heard from various railway authorities. But the higher cost of labour at the terminals, the reduced number of hours during which distribution from the terminals can take place, and the equally reduced number of hours at the works and warehouses during which goods can be received—all of these things mean that the pre-war conditions for the transport and general distribution of goods and merchandise can never return in the old form.

It is these changed conditions which have brought about the greatly extended use of road transport, and it follows that its

increasing application is not a temporary or accidental by-product of war conditions, but is the direct and logical outcome of shorter working hours, and the granting of increased wages to general transport workers, both of which have made inadequate and impossibly costly the pre-war method of terminal working at the goods yards, and the distribution of goods therefrom.

In whatever manner rail transport may be improved in future, the use of road transport vehicles must continue to extend, because, first, there must be well-defined limits within which the costs of the secondary operations of transferring goods from works or warehouse to the goods yard, the handling at the goods yard, possible transference en route, with a converse series of operations at destination, far outweigh the cost of the primary operations of transport by rail from town to town. Within these limits, motor transport will be employed increasingly. Secondly, the shorter working hours in factories generally make it impossible to accept the serious and inevitable delays incidental to the secondary operations referred to. Now as never before "time is money," and rail transport will be judged in future not only on the basis of its net cost, but also in relation to the time occupied in passing goods from point of despatch to destination. If the time occupied is too long in sending by rail, a higher transport cost will be justified by a sufficient saving in time.

It follows that a stage has been reached when road-transport vehicles must not be regarded merely as accessories to the business of the private user, valuable though they are from this standpoint. They must be recognized as the only solution whereby railways in this country can be worked efficiently under the new conditions which have been imposed; for it is by the organized use of road transport only that the congestion at the rail terminals can be reduced, whereby railway labour can be used more efficiently, railway wagons released, and a scientific re-organization of the railway system made possible.

When the whole question of road transport is approached from this wider point of view, it will be realized at once that the problem has not to be solved only in relation to the requirements of the

private user who acquires a road wagon for the speeding up of his business; it becomes a question also of its scope and application as a means of handling economically a maximum tonnage over a maximum distance on a regular and organized service. The alternative forms of road-transport wagons should be judged impartially in relation to these aspects of the problem, and each allocated to the functions it can best perform, so that the highest general efficiency is secured.

2. *The Economics of Steam-Vehicles.*—The object of this Paper is to emphasize the usefulness of the steam motor-wagon as the most economical and reliable form of road transport. In making this statement, however, the claims of the petrol and the electric vehicle respectively are not overlooked. Each has its sphere of advantageous application. Just as in the generation of power, the steam-turbine, the gas-engine, and the oil-engine have their proper and recognized spheres of usefulness, so it is with these three forms of road vehicles, whose respective provinces fall into such relation as not to conflict the one with the other.

For transporting a maximum tonnage over a maximum distance in a minimum time at minimum cost, the steam-wagon takes an easy lead over its rivals. For maximum mobility with lighter loads, and for special suitability for intermittent work the petrol-vehicle has undisputed claims, though its working costs are necessarily higher than in the case of the steam-wagon. The electric vehicle will be applied increasingly for town work and for short distance haulage. There is, of course, a dividing line between the respective spheres of these three forms of road transport, and on those dividing lines it may be a little difficult to come to a clear decision as to which side to incline towards, but such cases are in the minority; in the great majority of cases given, a clear understanding of the conditions that have to be met, and the decision as to choice of type to be applied, follow as a matter of course.

Having made the statement that steam haulage is the most economical form of road transport, it is necessary to give facts which will support it adequately. With this object, the Author

recently caused careful investigation to be made by a trained staff into actual running costs of various types of steam and petrol motor-wagons operating in the service of road-transport firms and private users who have adopted motor transport over a considerable number of years, and who have made an experienced study of working costs. Figures have been analysed which represent in the aggregate 15,000,000 ton-miles hauled. The capacities of the vehicles examined vary between 3 and 6 tons, and to obtain an accurate comparison each performance has been adjusted to give the cost of hauling 5 tons over 1 mile.

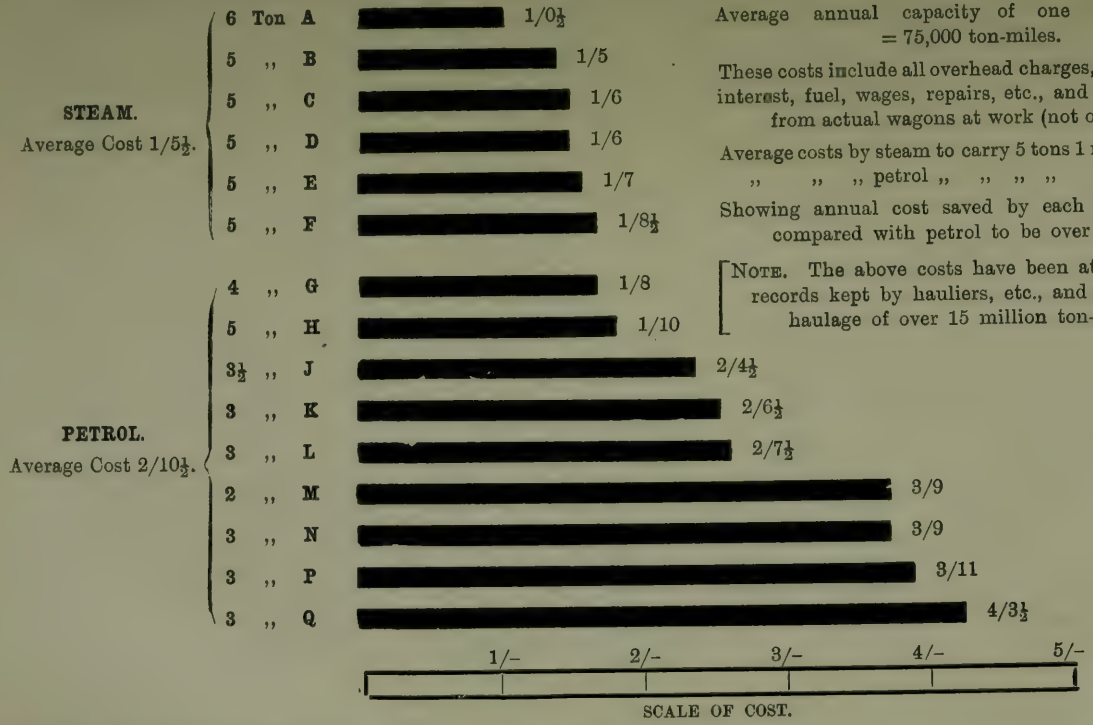
Analysis of Costs.—Table 1 shows the costs in six instances of steam-vehicle haulage and nine cases of petrol-vehicle haulage, representing approximately the work done by 100 steam-lorries and 100 petrol-lorries.

Table 2 (page 644) is an example of how the costs on Table 1 were arrived at for vehicles A and H. The mean load of the steam-wagon A was 6 tons, and that of the petrol H was 5 tons. These were chosen as typical heavy-duty vehicles working under very good conditions of loading, etc. The items "Fitters and Spares," "Coal," "Oil," "Tyres," were obtained from the owners as the actual costs booked to the wagons, whilst the other items were inserted as standard present-day costs, and were applied equally to all vehicles except when total costs as supplied by the owners included these.

Recent alterations in rates of wages have been taken into account so far as is possible. A 10*s.* per week rise for each of two men is less than 1*d.* per 5-ton mile.

The investigation covered the performance of one hundred steam-vehicles by five different makers of note, and also one hundred petrol vehicles by nine leading makers. The costs given include all overhead charges, depreciation, interest, fuel, wages, repairs, etc., and have been obtained from actual wagons on every-day commercial work, and are not makers' tests. To avoid any suggestion of preferential treatment for steam-wagons the depreciation of both petrol and steam-vehicles has been taken equally on the basis of $12\frac{1}{2}$ per cent, although it may be fairly

TABLE 1.—*Comparative Costs of Hauling 5 Tons per Mile by various Steam and Petrol Wagons.*



Average annual capacity of one 5-ton wagon = 75,000 ton-miles.

These costs include all overhead charges, depreciation, interest, fuel, wages, repairs, etc., and are obtained from actual wagons at work (not on test).

Average costs by steam to carry 5 tons 1 mile = 1/5½.
,, ,, ,, petrol ,, ,, ,, ,, ,, = 2/10½.

Showing annual cost saved by each steam-wagon compared with petrol to be over £1,000.

[NOTE. The above costs have been attained from records kept by hauliers, etc., and cover the haulage of over 15 million ton-miles.]

*** Since compiling the above, the price of coal has advanced 14/6 per ton, which adds approximately one penny to the cost per 5-ton mile. The annual saving is thus reduced to £950.

TABLE 2.

This Table corresponds to vehicles A and H on Table 1, thus:—

	Typical Steam-Vehicle (A).	Typical Petrol-Vehicle (H).
	£	£
Depreciation . .	180	180
Interest . . .	70	70
Fitters and spares .	188	145
Fuel . . .	90 tons at 35*s.*, 170	3,000 galls. at 3*s.* 2½*d.*, 480
Oil	250 galls. at 5*s.*, 62	170 galls. at 5*s.*, 42
Wages (man and lad)	430*	340
Tyres . . .	105	80
Insurance. . .	20	20
Accommodation .	20	20
Total costs .	£1,245	£1,377
Mileage . .	20,000	15,000
Cost per mile .	1*s.* 3*d.*	1*s.* 10*d.*
Cost per 5-ton mile	1*s.* 0½*d.*	1*s.* 10*d.*

* Higher wages due to longer hours.

Special note on increased cost of coal since this Paper was written:—

Extra cost due to 14*s.* 6*d.* per ton increase in cost of coal is approximately 1*d.* per mile, bringing cost of steam-wagon to 1*s.* 1½*d.*

claimed that the depreciation of the latter is very much less than the former. There are many steam-wagons 10 years old and over in constant and reliable service at the present time, and the City of Westminster has to-day three steam-wagons in regular service which are all 20 years old, and have been in commission for the whole of that period.

The result of this investigation, which is believed to be unique in its scope, is as follows :—

Cost of Hauling 5 Tons over 1 Mile.

	s.	d.
Steam Vehicles	1	5½
Petrol Vehicles	2	10½
Annual saving over 15,000 miles by use of Steam against Petrol Vehicles	£1,000 per vehicle.	

As stated above, these figures represent the actual total cost, and include :—

Interest, Depreciation	On a common basis per vehicle.
Repairs and Spares, Fuel, Oil, Wages, Tyres	Taken from actual records for each vehicle.
Insurance, Garage Accommodation	On a common basis per vehicle.

Three hundred miles per week or 15,000 miles per annum is taken as a reasonable performance for a commercial vehicle in an organized service run for profit.

Several interesting and significant facts transpired from the investigation. It was found for instance that whilst the average performance of each type of steam-wagon gave steadily consistent figures, those in connexion with petrol lorries varied very widely, and it would seem in consequence that they are more sensitive to varying factors in running conditions and also in the state of their repair and general adjustment.

In the case of petrol-vehicles, experienced large users were found to be convinced that the costs of upkeep and repairs in the 30 cwt. to 2-ton types were almost as heavy as in the 3 to 4-ton lorries, and hence when a reasonably full mileage per annum has to be traversed, the saving in the use of steam-wagons, when all costs are taken into careful consideration, is even more marked on the lighter loads.

3. *Carrying Capacity.*—Steam-wagons are normally of from 5 to 6 tons capacity, a 3-ton type being also employed to a lesser

degree. The standard 5 to 6-ton type regularly carries its full load, and when the local authorities allow increased axle-loads, they are loaded up to 8 and 10 tons. In addition, they often haul a trailer loaded with 3 to 4 tons, so that on long journeys wagon and trailer regularly transport from 8 to 10 tons per journey with two men. This performance as a regular commercial proposition is altogether beyond the scope of standard petrol-motors. The ability of the steam-wagon to transport these heavy loads successfully gives it a great advantage on a regular service where a large tonnage has to be moved.

To sum up the economic aspect of the subject, it will be clear from the facts here presented that a strong case is made out for a much wider application than hitherto of the steam-motor-wagon for all kinds of loads. Its relative economy and reliability is so great as to provide ample inducement for engineers and manufacturers to devote time and study to its further development and improvement.

4. *Steam Wagon Construction.*—There are three well-defined types as follows, Fig. 1 :—

(*a*) The *Over-Type*, as made by Foden, Clayton, Garrett, and others.

(*b*) The *Under-Type*, as made by Sentinel, Clayton, Atkinson and others.

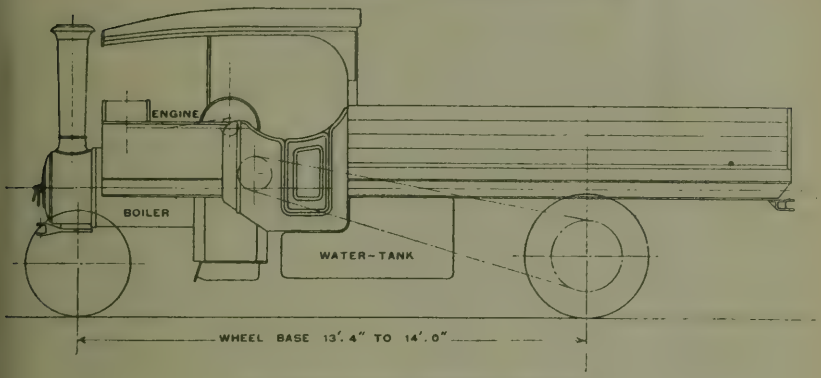
(*c*) The *High-Speed Engine Type*, as in the National steam-car, designed by Clarkson and familiar through its application to the London steam-omnibuses.

A brief review of the salient features of these three distinctive types will serve to show the present position of steam motor-wagon construction.

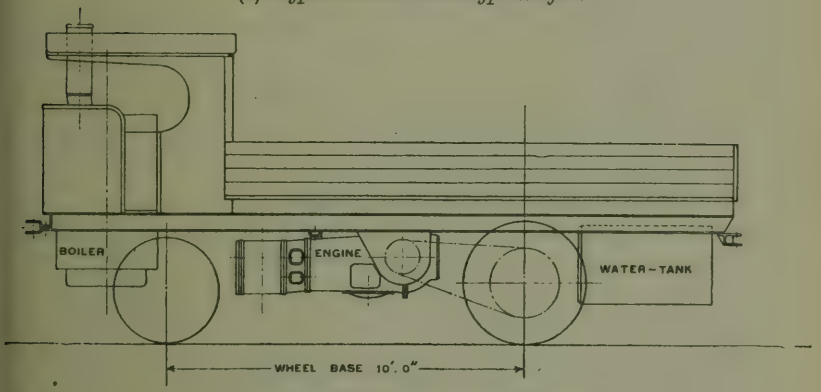
The Over-Type Wagon.

The over-type wagon is a direct development from the ordinary steam traction-engine. It derives its name from the manner in which the engine is mounted on the locomotive-type boiler, Fig. 2,

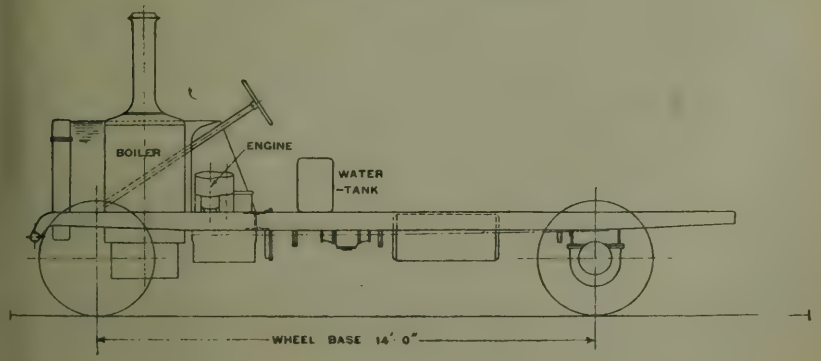
FIG. 1.—(*a*) *Typical 5-ton Over-type Wagon.*



(*b*) *Typical 6-ton Under-type Wagon.*



(*c*) *Typical "Clarkson" Type Wagon.*



the boiler itself being, in fact, the engine-frame. The engine is compound, the cylinders being usually of the following dimensions:—

High-pressure cylinder	4 inches diameter	Stroke 7 inches.
Low "	" 6¾ "	"

The cylinders are steam-jacketed, the jacket serving as a dome to the boiler, and it therefore carries the safety-valve. The steam regulator-valve is also suitably mounted in the cylinder casing, and is so arranged as to admit live steam to the low-pressure cylinder when required. There is likewise a diverting cock in the intermediate receiver, by which means both cylinders can exhaust direct to the atmosphere when each is working with live steam. The engine, therefore, normally works compound, but for quick acceleration after stopping in town traffic, a convenient movement of simple levers brings the double high-pressure into action. The crank-shaft carries fast and slow speed pinions which gear into spur-wheels on a second motion shaft. These spur-wheels carry the chain-sprocket which drives the rear axle through a roller-chain connexion.

The distribution valves to the cylinders are either ordinary flat D-valves or piston-valves operated by Stephenson link-motion. The front-axle steerage is usually of the form in which the axle itself turns on a centre pivot, the movement being controlled by a chain operating gear. There is a live back-axle, and in the best practice each rear-wheel is fitted with an expanding brake controlled by the foot of the driver. Robustness and accessibility, with corresponding reliability and ease of repair, are the outstanding features of this vehicle. In former days when steel tyres were invariably used, it is not too much to claim that the over-type wagon was the only type which gave satisfactory service, and it has done more than any other to maintain the confidence of users in the formative years during which road transport has been developed to its present stage. Now when all types of steam-wagons are mounted on rubber tyres, the greater margin of strength and reliability which the over-type wagon has always possessed still remains in reserve, and for continuous work in the hands of the ordinary driver, and for use on indifferent roads, it has no equal.

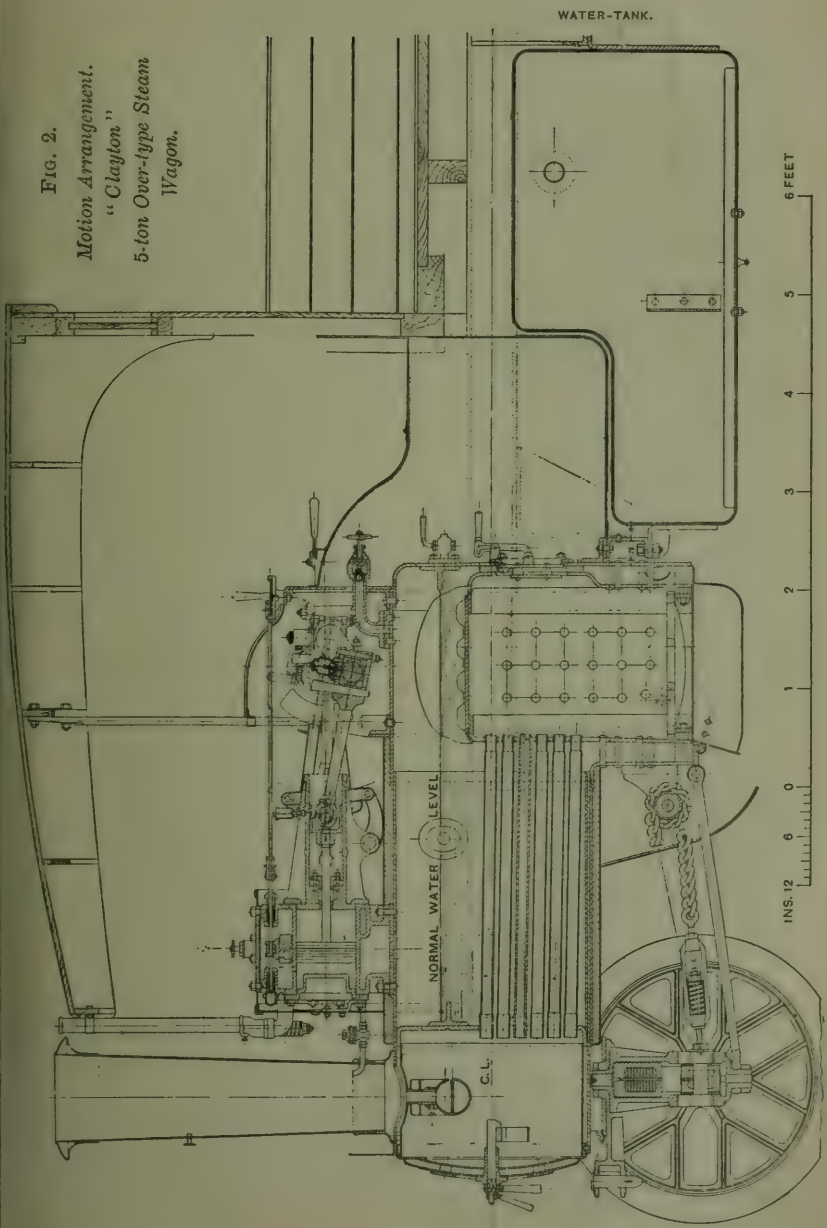


FIG. 2.
Motion Arrangement.
"Clayton"
5-ton Over-type Steam Wagon.

On the other hand, in this type of wagon the wheel-base is necessarily longer than in the alternative under-type, owing to the form of boiler and arrangement of mechanism, and in the rough and tumble of commercial propaganda this comparison is usually enlarged upon unduly so as to discredit the over-type. As a maker of, and a strong believer in, both types of steam wagon, the Author deprecates this tendency, for both have ample scope and innumerable spheres of work, and each has distinctive merits.

THE UNDER-TYPE WAGON.

This wagon is so-called because the engine is quite separate from the boiler, and is fixed to the chassis underneath the body of the wagon. A vertical cylindrical boiler is adopted invariably with central furnace in which water-tubes are introduced. A superheating coil is inserted in the upper part of this furnace and the whole of the steam is dried and superheated on its way to the engine. As the latter is placed under the body of the wagon, and is, therefore, not conveniently accessible, the utmost simplicity is desirable. In consequence, compounding and the two-speed gearing are dispensed with. The engine is made larger and more powerful, and to provide for the wide variations of power required for running on the level, and for hill climbing respectively some suitable form of variable expansion gear is desirable. The Sentinel engine has drop-valves actuated by cams. The cam-shaft is arranged to slide axially under control from the driver's operating gear, and in this way cams with profiles suitable for early and late cut-off in the ahead direction of rotation, and for reverse are respectively brought to operate on each set of valves at the will of the driver. In the Clayton under-type a larger engine, Fig. 3, is employed, Table 3 (page 652), fitted with piston-valves operated from eccentrics mounted on a lay shaft. A special device of great simplicity is used to control the angle of advance and throw of the eccentrics, so that a full range of cut-off from zero to maximum is under the control of the driver as shown in Fig. 4 (page 654) and Fig. 6 (page 656). By the same means the eccentrics are brought into the reverse position. In both the Sentinel and Clayton wagons the engine

FIG. 3.—*Assembly of Engine for 6-ton "Clayton" Under-type Wagon.*

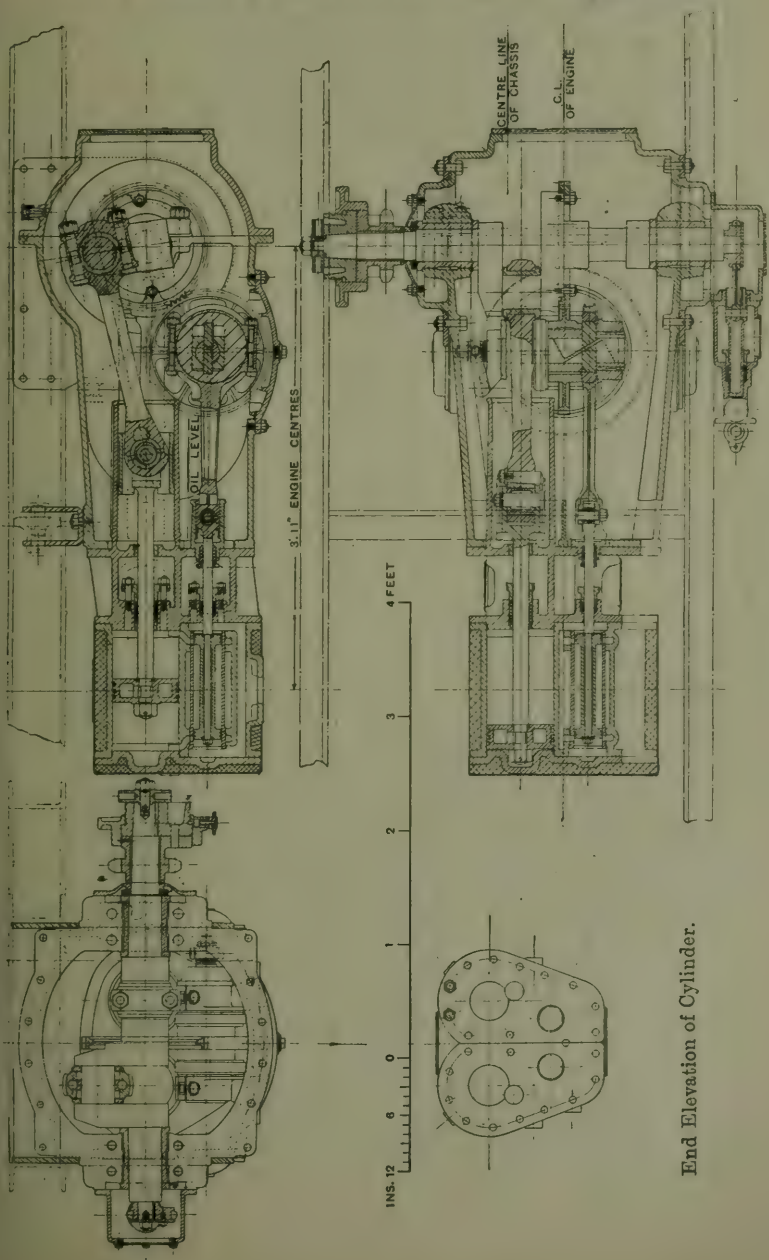

End Elevation with End Cap Removed.
Sectional Elevation through Cylinder and Valve.
OIL LEVEL
3.11" ENGINE CENTRES
CENTRE LINE OF CHASSIS
C.L. OF ENGINE
INS. 12 6 0 1 2 3 4 FEET
End Elevation of Cylinder.
Half Sectional Plan through Cylinder and Half through Valve.

TABLE 3.—*Leading Dimensions of Wagons Illustrated. Year*—1920.

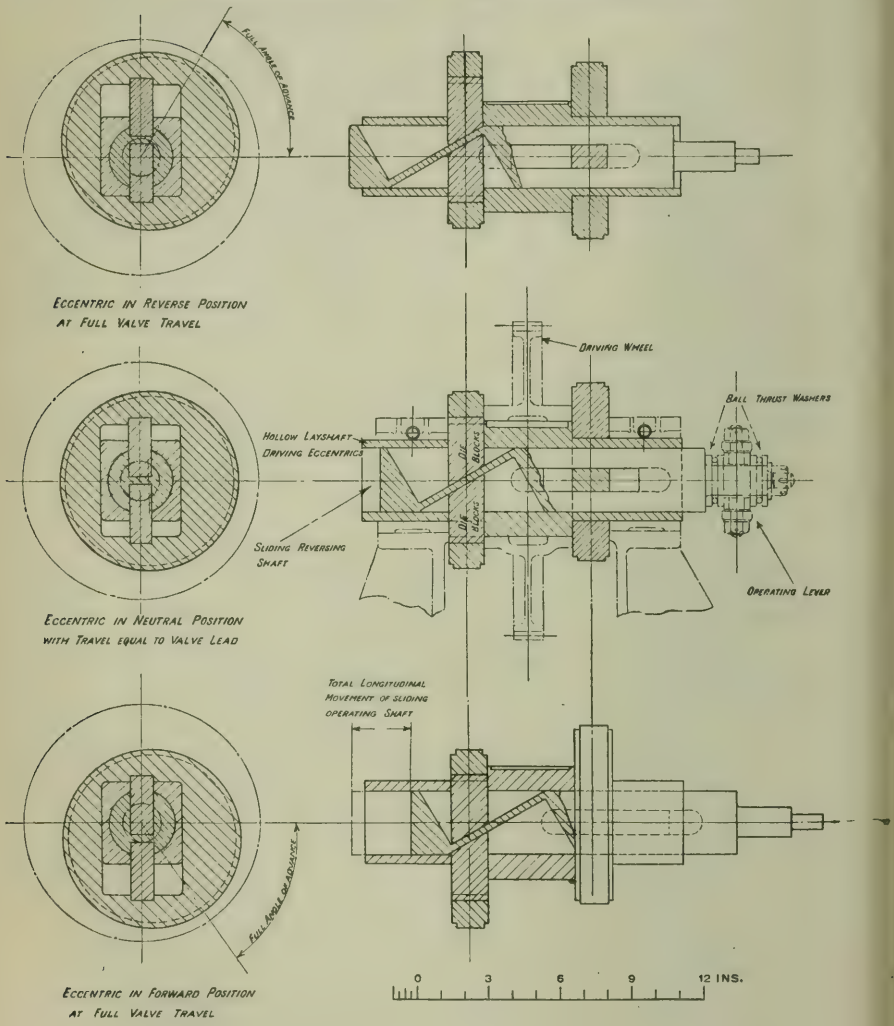
Fig.	Name of Vehicle and Makers.	Net Load. Tons.	Engine. Bore and Stroke.	Engine. B.H.P. at Normal Speed.	Type of Boiler.	Fuel. Recommended.	No. of Speeds.	Final Drive.	Type of Wheels.
10, Pl. 5, and 2 (page 649)	Clayton over-type	5	4 in. and 7¼ in. × 7 in. stroke.	35	Loco	Coke or Coal	2	Roller Chain	Cast Steel
1*b* (page 647)	Clayton under-type	6	2 H.P. cylinder 7 in. × 10 in. stroke.	35	Vertical water-tube	Coke or Coal	1	Roller Chain	Cast Steel
11, Pl. 5 .	Foden over-type .	5	4 in. and 6¾ in. × 7 in. stroke	35	Loco	Steam-Coal	2	Chain	Cast Steel
12, Pl. 5 .	Garrett ,, ,, .	5	4 in. and 6¾ in. × 7 in. stroke	35	Loco	Coal	2	Chain	Cast Steel
13, Pl. 6 .	Mann ,, ,, .	5	4 in. and 6¾ in. × 8 in. stroke.	30	Loco	Coal	3	Chain	Steel
14, Pl. 6 .	Sentinel under-type	6	2 H.P. cylinder 6¾ in. × 10 in. stroke	35	Vertical water-tube	Coke. Steam-Coal or both	1	Roller Chain	Cast Steel
15, Pl. 6 .	Clarkson high-speed engine type	3	3½ in. and 6 in. × 4 in. stroke.	—	Vertical thimble	Coke	2	Worm-gear.	Cast Steel

TABLE 3—*continued.*

Name of Vehicle and Makers.	Size and Type of Tyres.	Track. Centre to Centre.		Wheel-Base.	Length Overall.	Length Body Space.	Tare Weight, Chassis.
		Front.	Rear.				
		ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	
Clayton over-type . .	Rubber 720 × 160 850 × 160 T.	4 0	5 10½	14 2	21 6	12 0	4 ton 18 cwt. 3 qr.
Clayton under-type .	Rubber 720 × 160 850 × 160 T.	5 6	5 1¾	10 0	19 9	14 0	4 ton 15 cwt.
Foden	Rubber 850 × 160 1050 × 160 T.	4 0	5 11	14 2	23 0	12 0	—
Garrett	680 × 140 870 × 160 T.	4 6	6 3¾	13 4	22 2	12 0	—
Mann	Rubber 850 × 160 1070 × 160 T.	3 5	5 4½	12 5	21 2	12 8	5 ton
Sentinel	720 × 160 850 × 160 T. fitting	5 5	5 1¼	10 4½	20 6	14 6 overall	4 ton 19 cwt. 3 qr.
Clarkson	—	5 10	5 6½	14 0	19 6	—	—

FIG. 4.

Eccentric Reversing Gear. "Clayton" Under-type Wagon.


FULL ANGLE OF ADVANCE
ECCENTRIC IN REVERSE POSITION AT FULL VALVE TRAVEL
DRIVING WHEEL
BALL THRUST WASHERS
HOLLOW LAYSHAFT
DRIVING ECCENTRICS
DIE BLOCKS
SLIDING REVERSING SHAFT
OPERATING LEVER
ECCENTRIC IN NEUTRAL POSITION WITH TRAVEL EQUAL TO VALVE LEAD
TOTAL LONGITUDINAL MOVEMENT OF SLIDING OPERATING SHAFT
FULL ANGLE OF ADVANCE
ECCENTRIC IN FORWARD POSITION AT FULL VALVE TRAVEL
0 3 6 9 12 INS.

is used as a brake when running down gradients ; the valve-gear is brought into the reverse position, and as the engine is running ahead with the steam shut off, it immediately acts as an air-compressor pumping compressed air into the intermediate steam-pipe between stop-valve and engine ; a relief-valve is fitted to this pipe which can

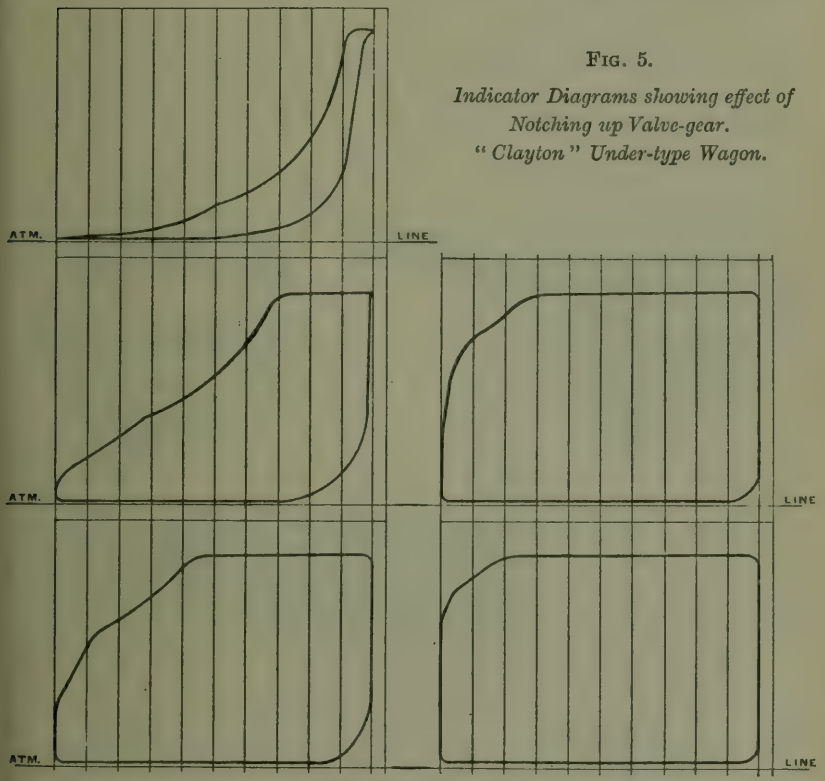


FIG. 5.

Indicator Diagrams showing effect of Notching up Valve-gear.
"Clayton" Under-type Wagon.

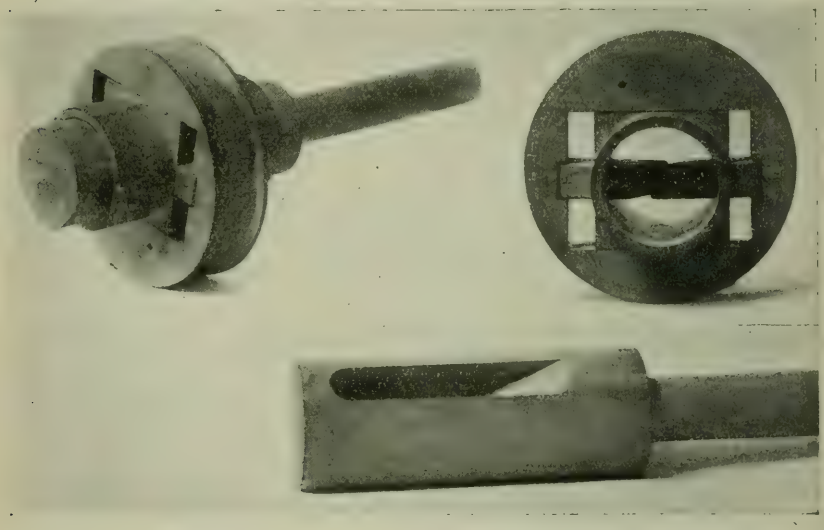
Scale 180 lb. = 1 inch.

be opened by a pedal under the control of the driver so that the back pressure can be relieved when the braking effect is too great. With this convenient arrangement, the expanding rim-brakes on the rear road-wheels are seldom required. The sprocket on the end of the crank-shaft, driving on to the live back-axle with a roller chain constitutes the complete transmission system.

Indicator diagrams showing the effect of notching up the valve-gear of the Clayton under-type wagon are shown in Fig. 5 (page 655).

The Sentinel cross-tube boiler illustrated in Fig. 7 is well known.* In the Clayton boiler, Fig. 8, it will be seen that a corrugated furnace is adopted with a special double set of curved water-tubes projecting into the furnace gases in a vertical plane; each tube has an equal chance of deriving heat from the furnace and, being arranged vertically, the circulation and evaporative efficiency are

FIG. 6.—"*Clayton*" *Eccentric and Operating Gear Assembled and Dismantled.*



correspondingly improved. The elasticity of both furnace and tubes enables the boiler to be forced without the slightest danger, and the improved circulation keeps the tubes clear of deposit.

The steering is by pivoted wheels on a fixed front-axle. It will be seen from the Figs. that the style of boiler and arrangement of under-type engine enables a short wagon to be constructed without reducing the size of loading platform. When mounted on rubber tyres and used on first-class roads without too many gradients, the

* *See* Proc. I.Mech.E., 1919, Figs. 46–47, Plate 26.

Vertical Under-type Boilers.

FIG. 7.—"*Sentinel.*"

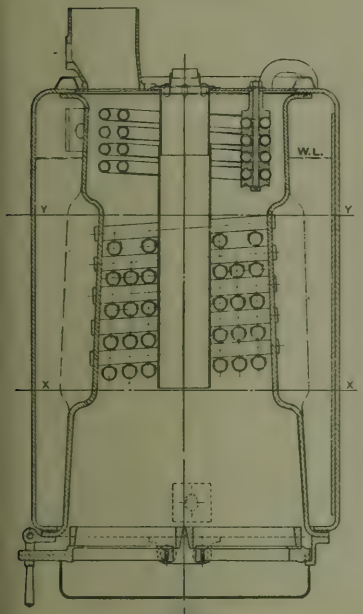
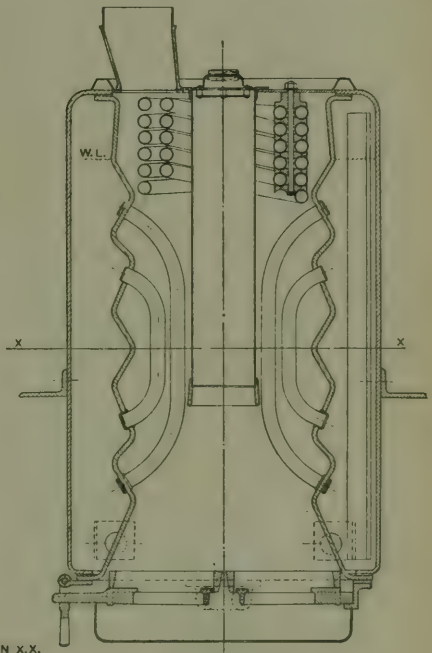
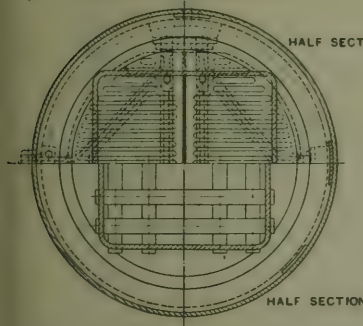
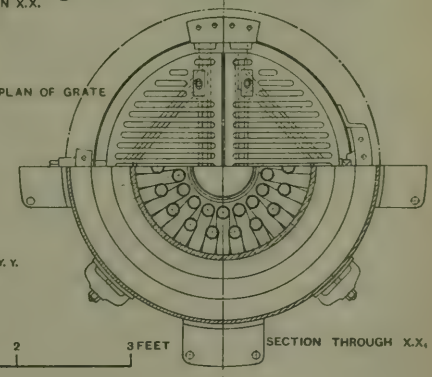


FIG. 8.—"*Clayton.*"







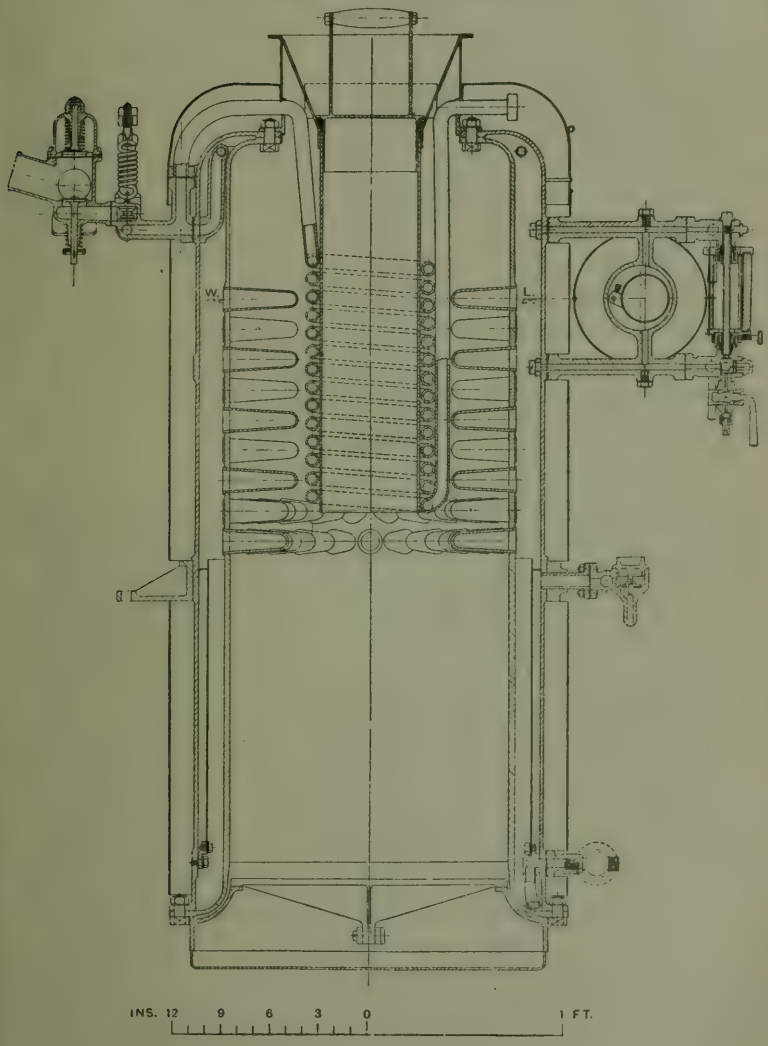
under-type wagon is most suitable, and it is being employed increasingly in this connexion.

The choice as between over-type and under-type must be regulated by the conditions which have to be met. In the case of the individual user who has one or two wagons and where the driver has to do his own repairs, the inherent advantages of the over-type, with its open engine and accessible mechanism, coupled with its simplicity and strength, constitute a powerful recommendation; also for hilly or rough roads or for combination with trailers it has a distinct and proved advantage. Speaking generally, the 5-ton over-type may be claimed as a universal machine. On the other hand, for maximum distances on first-class roads the under-type may be applied advantageously. Both types will have their proper uses for many years to come.

High-Speed Engine Types.

Mr. Clarkson, whose name is associated with the development of the steam-omnibus which until recently was so well known on the London streets, has given much time and thought to the production of a 3-ton steam-lorry, which differs radically from the vehicles which have been already described. The essential difference is that the engine (for dimensions of which see Table 3) is of the compound type with cylinders arranged V fashion having connecting-rods coupled to a single crank. Each cylinder is fitted with a piston-valve driven by an ordinary eccentric. The speed is 600 r.p.m., and the engine runs in one direction only. A clutch has, therefore, to be introduced and reversing is affected through the gear-box, which likewise arranges for two forward speeds. A live back-axle with worm-drive is employed so that the general style of mechanism from engine to driving wheels follows very closely well-understood petrol-lorry practice. The boiler, which is shown in Fig. 9, is also of a special type, and consists essentially of an outer and inner shell with concentric space between for water and steam. A series of solid-ended tubes project like spikes into the hot furnace-gases, and these have been found to

FIG. 9.—"*Clarkson*" *Vertical Boiler for Coke.*



keep free from deposit. The exhaust-steam is condensed in an atmospheric condenser which has more or less the form of a motor-car radiator. Mr. Clarkson has explained other details of his designs in his Paper, "Steam as a Motive Power for Public Service Vehicles."* The Author has had no working experience with this type of vehicle, and, therefore, he is not competent to judge of its relative reliability and working efficiency. There can be no doubt, however, that Mr. Clarkson's designs raise the whole question of the advisability of introducing several of the most vulnerable points of the petrol-wagon into a steam-wagon which the more orthodox vehicles, both of the over-type and the under-type, have so far been able to avoid. Mr. Clarkson has consistently adhered to his type of machine for a good many years now, and much credit is due to him for the practical success he has achieved, and the future application of his type of steam-wagon will be watched with keen interest by those connected with the industry.

5. *Future Development.*—If the permanent functions of road transport come to be regarded by those in authority on the lines suggested in the opening section of this Paper, the evolution of motor vehicles up to 10 tons carrying capacity may be expected, and these will most certainly be "steamers." At the other end of the scale, investigations have brought one to the conclusion that there is a wide field for a light mobile "steamer" of 3 tons capacity. It is, therefore, at the upper and lower limits of carrying capacity that there seems to be the most room for new ideas both on design and manufacture. Existing designs of 5 to 6-ton vehicles, both over-type and under-type, by leading makers may be considered to be fairly well stabilized for some years to come, although further attention may well be given to methods of conserving lubricating oil.

As the large savings which are possible through the use of steam-wagons become more generally known, there will be an increasing tendency on the part of transport users to apply them; everything that can be done to reduce the consumption of costly imported fuel,

* Proceedings I.Mech.E. 1906, p. 753.

such as petrol, is worthy of the skill and application of British engineers.

The Author desires to acknowledge with sincere thanks the assistance rendered to him by Mr. H. L. Wimbush in the preparation of this Paper.

The Paper is illustrated by Plates 5 and 6 and 9 Figs. in the letterpress.

Discussion.

The President said he was sure it was the wish of the members to accord a very hearty vote of thanks to the Author for his most interesting Paper, which dealt with a question of the utmost importance. He hoped Sir Henry Fowler would give his views later on of the railway aspect of the question. The data connected with the investigation on costs carried out by the Author, and given at the beginning of the Paper, would of themselves be of great value to the Proceedings.

The resolution of thanks was then put and carried by acclamation.

Mr. W. T. Bell, O.B.E., desired to add his meed of praise to that of the President for the convincing Paper that had been presented by Mr. Robson. He wished in the first place to thank the Author for the excellent manner in which he had made out the case for the steam-wagon, because it was apparent from the figures submitted that the steam-wagon led and the others were nowhere. It might, of course, be said that manufacturers of steam-wagons naturally were prejudiced, but he thought the figures in the Paper would be difficult to controvert. He also thanked the Author for his reference to the steam-wagon manufactured by his company,

(Mr. W. T. Bell.)

Messrs. Robey and Co. It was very interesting to learn from the Paper that the Author's firm was taking up the manufacture of the under-type wagon after they had had such a long experience of the over-type. He confessed that the advantages appeared to be all on the side of the over-type wagon. It was true that in most makes of the over-type it was difficult to obtain the legal axle weights and still carry the 5 tons, and he noticed that the Author touched on that point rather delicately on page 646. It was possible, however, to produce an over-type wagon and at the same time fulfil the legal requirements, but he was sure that, if the under-type wagon proved to be the better wagon of the two, they would all congratulate the Author on his boldness in bringing it about.

He noticed that the Author proposed to use piston-valves for the under-type engine, and he hoped they would be successful. Apparently the Sentinel type of wagon started off with piston-valves and then developed into poppet-valves, and it would be interesting to find out from experience how the piston-valve really worked.

Sir HENRY FOWLER, K.B.E. (Member of Council), said that, having been the first observer of a steam-driven lorry which went out on official trial in this country, at which trials he had the pleasure of meeting a prominent Member of the Council, he could not help looking back and seeing the great developments which had taken place in these vehicles since that time. He had been particularly interested in what the Author had said with regard to electric vehicles, because he represented a firm which had, he believed, the largest fleet of this type of motors in the country, which they found extremely useful for town deliveries. He was sorry the figures which he could put forward, and which had been published quite recently in *Motor Transport*, could not be compared with those the Author had given, because the latter had evidently been chosen from typical heavy working under good conditions of loading; these conditions were one of the great essentials for getting the best service not only out of steam-vehicles but any type of motor, and one which railway companies had very great

difficulty in finding. In view of the constant changes in the rates paid for labour at the present time it would add materially to the usefulness of the Paper if the Author would state, in reference to the figures given on page 642, the date to which these figures applied, as this would be of use for future reference.

With regard to the life of vehicles, his firm purchased two motor vans in 1903 which had only just been disposed of, although for a very considerable time they ran for twenty hours out of the twenty-four. They had a few steam-vehicles, one of which had already had a life of sixteen or seventeen years. A tractor built at Lincoln had a life of about ten years and was still working satisfactorily. One point which had not been touched upon, but which was of vital interest from a warehousing standpoint, was the fire risk with steam-vehicles. That subject had received much greater consideration of late years than in earlier times, but it was a factor which militated against the use of steam-vehicles under certain conditions. He was sorry that from a purely railway standpoint he could not discuss the question which the Author had touched upon in the early part of his Paper in the time at present at his disposal. It must be remembered, however, that motor-vehicles at present ran on a permanent way—the roads—which was practically speaking free. He lived on the side of a main road between two cities about 60 miles apart, and he knew the difficulty he experienced in using a push-bicycle over that road at the present time, and more so with a fairly light car on four wheels. Undoubtedly this question of roads was a subject which must be handled before the motor-vehicle could be satisfactorily dealt with on the lines suggested by the Author, as many of the roads were at present in a disgraceful state. Until a central authority was established, the roads would not be put into a condition in which they could be used for steam or petrol traction to the greatest advantage, and the question naturally arose as to who was to pay for this. He did not wish to discuss the question of the new taxation of vehicles, but he thought it would hardly meet the state of things which the Author laid down as likely to occur in the future.

Mr. THOMAS CLARKSON thought the members were all of one mind that the Author had rendered very great service in focussing attention on the steam-vehicle at the present time when the very serious condition of transport all over the country was borne in mind. The development of road transport was largely the result of the development of the internal-combustion motor, on the improvement of which a great deal of money had been expended. He thought as steam-engineers they should not be guilty of prejudice; they should face the problem with an open mind and recognize the excellent work which had been done by the petrol engineer in solving various problems and particular aspects of road transport. Broadly speaking, the subject might be divided into three parts. As in the old days there were the horse, the harness, and the vehicle, so still there were the horse or the motor, the harness or the transmission gear, and the vehicle. Apart from the motor, a great deal had been done in developing the efficiency of the harness and the vehicle itself. It was necessary to have that harness sound and serviceable. The harness consisted, in the case of the internal-combustion motor, of the clutch, the gear-box, and a live axle, either with a worm drive or spiral bevels. Those parts, which were formerly very troublesome and expensive to maintain, had now been brought to a high degree of efficiency. One frequently heard the remark made that a driver did not know he had a clutch or a gear-box or a live axle.

In considering the further application of steam to road transport, he thought the Author was undoubtedly correct that the heavier duty of 10-ton loads would almost certainly be done by the steam-vehicle, but he went further and suggested that the lighter and quicker and more "nippy" type of transport could also be done by the steam-vehicle. They had to develop that new breed, and he was very sorry that engineers had somewhat neglected that rather promising field. It was now recognized that the petrol-vehicle had been brought to a high degree of efficiency; it was a commercial proposition; but its success was becoming its ruin. To be fruitful and multiply was supposed to be a sign of prosperity, but the petrol-vehicle was multiplying so fast (he believed that in America

alone the annual output was approximately 2,000,000 cars) that he was told that by the end of the year the world's total supply of motor spirit, of some 11,000,000 tons per annum, would be quite inadequate to satisfy the demands of the business that would then exist. The price of petrol had advanced by some 200 per cent; it was now three times dearer than in pre-war days, and they were informed that by the end of the present year it might have increased to 5*s.* or 6*s.* a gallon, which meant that a 3-ton petrol-lorry would cost 10*d.* a mile for fuel alone. That was a very serious position. Therefore, the steam-engineer had to consider whether he could not provide a horse and harness it to a vehicle that would use a diet which was not so costly, in fact, which could use not only a cheaper diet, but one made in this country. Internal-combustion engineers said the solution lay with alcohol. Alcohol they knew had been a dangerous substance to many men, and it indicated the desperate nature of the situation when it was stated that alcohol was to be their salvation! He believed the Nizam of Hyderabad was now cultivating the mahua tree, which produced blossoms weighing 2 cwt. per annum, from which alcohol could be distilled in considerable quantities. He had heard it stated that, if an area in equatorial Africa corresponding to about a square inch on a wall map were systematically cultivated, sufficient alcohol could be produced to satisfy the requirements of the world. But there was a long way to go before that was ever realized, even if it was, and meanwhile it was necessary to carry on.

There were fuels in this country, both solid and liquid, which the steam-motor could use. There were cheaper forms of liquid fuel like creosote, which at the present day could be bought at 1*s.* a gallon, and a 3-ton lorry could run four miles on that fuel, which represented a fuel cost of 3*d.* a mile. That, at the present day, was nearly half the cost of petrol at current prices, without regard to the probable considerable increase that might occur in the near future. There was now considerable experience of the type of steam-generator necessary for the lighter kind of vehicle—a special type which could not only be used with liquid but with solid fuel. Hard coke existed in this country. Gas coke could be used, but he

(Mr. Thomas Clarkson.)
found that the best solid fuel was hard coke or furnace coke broken up to about road-metal size with the dust removed. That fuel would be consumed at the rate of approximately 6 lb. per mile with a 3-ton load. At £2 a ton that represented $1\frac{1}{2}d.$ a mile for fuel. There was nothing to-day anywhere near it in the cost of operation, and he thought it was well worth the attention of British engineers. The petrol engineers deserved a warm tribute for what they had done in developing the other parts of the vehicle, and steam engineers should have no hesitation in accepting the results of their labours and the large amount of money which had been expended in that development; but they must harness to it a motor which could use a cheaper fuel. It was largely a fuel problem. He desired, before sitting down, to express his grateful appreciation of the very kind remarks the Author had made with regard to his (Mr. Clarkson's) efforts in the last twenty-five years.

Mr. L. A. LEGROS, O.B.E., said there was one aspect of the question which he thought all the members would do well to realize much more thoroughly than was the case at present, namely, that the vehicle and the road formed together one unit for transport purposes, and they should never be considered widely apart. They were just as much a pair as were the railway train and its track, or the barge and the canal. There was a point to which he wished to refer in connexion with the present development of putting the roads and their accessories under the ægis of the chief of the railways. What would have happened to the railways if they had been put under the ægis of the head of the canals, the previous transport medium in this country? Would the railways of this country have been so rapidly developed if they had been put under a Canal Board, and could it be expected that the roads of this country would be developed if they were subject to a Ministry chiefly interested in railways?

Another side of the question with which he wished to deal was that of the tyres on which the vehicles ran. Tyres, as much as the quality of the road surface, had a very great influence on the maintenance and life of the vehicle. It afforded him much pleasure

to hear the Author state that a greater number of steam-wagons were now being made with rubber tyres. That, of course, would have a very great bearing on the life of the roads and on their carrying capacity; this would be further increased if the roads were put into a better condition of dustlessness and freedom from water penetration, such as should be expected if they were properly and carefully managed in the future.

It was not, perhaps, perfectly fair to compare the steam-vehicle with the petrol-vehicle in the way in which those two classes of vehicles were frequently compared, but it must be remembered that the steam-vehicle had three times made an effort to come into existence—in the early "Thirties," in the "Sixties," and again in the "Nineties"—and it was only at the last effort that for ordinary transport vehicles it had been able to achieve success. It was very much older than the petrol-vehicle, which began later in the "Nineties," and as a commercial vehicle practically did not exist during the last century, for it was then hardly beyond its adolescent stage. It took ten years or so for any type of traction to become sufficiently developed to be reliable from the commercial point of view, the rare exceptions being a few special devices developed under war conditions. The steam-vehicle had the great advantage derived from its close kinship to other practice, and particularly traction-engine practice, in the past, which had assisted its development, and it had taken full advantage of that practice to develop rapidly. It was noteworthy that the Author's firm had great experience in tractors, and the fact that both under- and over-types of steam-wagon were being made by the same firm would enable most interesting comparisons to be effected of performance and adaptability to different classes of road-transport work. He thought it would be of interest if the Author could add details to Table 1 showing which of the vehicles were rubber-tyred.

Dr. H. S. HELE-SHAW, F.R.S. (Member of Council), said that he had not intended to join in the discussion, but he presumed that Sir Henry Fowler was alluding to him in the remarks he had made with regard to the beginnings of automobilism, and as a

(Dr. H. S. Hele-Shaw.)
matter of fact, he was a judge at all the early trials. It was at these trials he had first met Sir Henry Fowler as quite a young and unknown man in those days, who had been of the greatest assistance to the judges. Sir Henry was then serving the Lancashire and Yorkshire Railway, and they had the courage to start a fleet of motor-vehicles, as that enterprizing company realized that their chief difficulty was in connexion with the terminals. Sir Alfred Holt, the Liverpool shipowner, who was one of the most far-seeing men he had ever met, used to say that the handling of the goods was the giant while their transport was the dwarf; the giant was getting greater all the time and the dwarf was growing less. He was very proud to hear from Sir Henry that the work put into those early vehicles was of such an excellent nature, and it was a great credit to the British manufacturer that those vehicles were running to-day. Personally he (the speaker) had always believed in the future of heavy commercial vehicles as a great factor in the future in this country, and that the real question of the future which concerned automobile engineers was the heavy motor transport question.

The fuel question was the great problem of the day; thus America, which formerly supplied the whole of our liquid fuel, had now over-reached its own supply, owing to the prodigality with which the liquid fuel was being used. The members would recollect the man who, when the suggestion was made to him that he should consider posterity, asked why he should consider posterity, as posterity had done nothing for him. That idea must have been possibly responsible for the waste of millions of gallons of liquid fuel. It was an extravagance that everyone now looked back upon and deplored, all the more because it was not posterity but themselves who were suffering, for America had now not only over-reached its own supply, but, by the end of this year or certainly next year, would be compelled to import more than one-seventh of its liquid fuel from outside. Several years ago the Motor Union appointed a committee, of which he was the chairman, to look into the question. That committee tabulated all the various sources of supply, but at that time the pinch was not

felt, and very few people took any notice of the report. The figures, however, indicated unmistakably what was now occurring —that an enormous industry in motor vehicles was being developed all over the world, and that the problem which had to be faced was the serious one of supplying fuel with which to run those vehicles. Although wonderful supplies were being opened up in Mexico, the East Indies and Rumania, it was quite clear that the exhaustion of the supply of liquid fuel was going to be immensely more rapid than the exhaustion of the coal supply. That was the problem which faced engineers at the present time, and he had therefore listened with the very greatest interest to a Paper dealing with the progress of coal-burning motor-vehicles.

He desired to be allowed to pay a tribute to the work that had been done by Mr. Clarkson. He remembered in the early days, when Mr. Clarkson was fighting the battle of the steam-vehicle car, seeing him, he believed with a partner, Mr. Capel, at various trials nearly twenty-five years ago. Mr. Clarkson's faith never diminished in spite of the terrible difficulties he encountered, particularly with the boiler and the burner. Mr. Clarkson used to drive his vehicles himself in those trials, facing obstacles that would have daunted most other men, but he persisted in his efforts, and they all knew that he was not so far wrong in the views he then held.

It was a pleasure to see from the Paper that Lincoln was turning out first-class engineering work, and stood higher than it ever did, and in the matter of road transport, as well as in agricultural machinery, was keeping up the reputation of the old country all over the world.

Captain G. H. SAVAGE, R.A.S.C., said that when the question of economical running was being discussed, and the two better known types of vehicles, namely, steam and petrol, were being compared from this point of view, he thought that mention should be made of a gas-producer plant designed by Col. D. J. Smith. This plant supplied producer-gas in place of the petrol on internal-combustion engined road vehicles, and could be used on the ordinary petrol

(Captain G. H. Savage, R.A.S.C.)

lorry. He understood that this plant burnt either anthracite or coke. The comparative costs were given in a Paper read in January last before the Institution of Automobile Engineers, by Col. D. J. Smith.

He would quote only one paragraph from the Paper:—"This Table of comparative costs indicates that by using producer-gas in an internal-combustion engined vehicle, the steam-vehicle is no longer the cheapest in fuel cost, and it is in the weight of fuel, however, that the greatest saving is accomplished; the steam-vehicle uses about nine times greater weight of fuel per mile than the producer-gas vehicle." He brought the question up because it seemed that it might have an important bearing on future events if petrol gave out as had been predicted.

Mr. P. W. ROBSON, O.B.E., in reply, said he was extremely obliged to all the members who had taken part in the discussion, and who had dealt with the points of the Paper so intelligently and sympathetically. His chief object in putting forward the Paper arose from the realization by many of two main factors—first, that the supply of petrol fuel was in jeopardy so far as the quantity was concerned, and secondly that road transport was an absolute requirement and a necessity of modern life. The laymen of the country had grown to associate road transport almost entirely with the petrol-vehicle. Mechanical engineers desired to tell them that, if the petrol supply was in danger, road transport was in no danger; that in any event, by using home fuel, the country could do road transport much more cheaply and efficiently than at present. In the figures that had been prepared he had done his best to be impartial. He had satisfied himself that the records were carefully prepared by the firms by whom they had been supplied, and in every way he had done his best to put forward real solid facts against which it was possible to write his name.

In reply to Mr. Legros' question, he was able to say that all the vehicles were rubber-tyred. As between the various types of wagon he was looking forward to a much larger and wider application of the steam-vehicle to road transport. It was no

longer a matter of difficulty to make the over-type wagon come within the limit of legal weights, as Mr. Bell said. The choice as between the over-type wagon and the under-type wagon hardly rested on that basis. He believed that amongst other things the under-type wagon was going to be used, and used increasingly, for long distance runs. In that connexion, provided the roads were good and the conditions were not unduly severe from the point of view of gradients and so forth, the under-type wagon had advantages. The under-type wagon as well as the over-type would undoubtedly have a very large field of use. He had indicated towards the end of the Paper that considerable developments must be looked for in connexion with what Mr. Clarkson had so appropriately termed a "nippy" vehicle. At the present stage he personally would not presume to say what the final type of such vehicle would be. Mr. Clarkson had put forward a design which warranted careful study.

The subject of the construction, durability, and cost of roads was a very important one, but he had come to the conclusion that it was secondary to the demands which had been produced by the general shortening of hours. Shortening of hours in connexion with work generally in all departments of business and in factories had produced one of the biggest revolutions that the country was being called upon to meet. All those who were responsible for large works must have felt that. The question of the time element, the short working day within which they had to crowd their efforts, was going to determine all their requirements and to decide what should be used and what should not be used. He had tried to make clear, for the reasons which were given in the Paper, that those shorter hours, apart from anything else, were going to demand a continual increase in the use of road transport vehicles, and he thought the roads would have to be made to accommodate themselves to those determining conditions. A question had been asked with regard to the fire risk. Perhaps there was a slight fire-risk. Whether they were making steam-navvies or steam-wagons, manufacturers could not do everything; they had to take the conditions as they found them. He was bound to say,

(Mr. P. W. Robson.)

however, that the number of cases which came before him, in conducting a steam-wagon business, where the fire risk was the determining factor, was singularly small.

He was greatly obliged to Dr. Hele-Shaw for his helpful remarks. The suction-gas plant wagon was a development which he was sure everyone would watch with interest, but it was in too early a condition of evolution to be dealt with at present. If his Paper had succeeded in drawing attention to a solution for the growing scarcity of petrol fuel, which otherwise might cause the utmost anxiety to everyone, he was quite satisfied that it had served its chief purpose.

SOME LINCOLNSHIRE OIL-ENGINES.

By F. H. LIVENS, of Lincoln, *Member.*

Since the last visit of The Institution of Mechanical Engineers to Lincoln in 1885, a most important engineering industry has developed in Great Britain, and particularly in this county, in the production of a new motive power, the influence of which throughout the world can hardly be estimated, namely, the employment of the heavier oils as liquid fuel admitted directly to the engine cylinder.

It is true that there had been some use before 1885; for instance, the Brayton engine from America was introduced into this country by a Nottingham firm in 1878, whilst the Lenoir engine from France, and the Spiel engine from Germany arrived in 1883. The first ran on a heavy oil of a density corresponding to what we know as paraffin, but with a lower flash-point than now stipulated, whilst the second and third required a petroleum spirit similar to the present petrol.

The Proceedings of this Institution are singularly barren of contributions as to this development, but there is excellent information to be found in many text-books (particularly "Gas and Petroleum Engines," Professor Robinson's 2nd Edition, 1902, and "The Gas,

Petrol and Oil Engines," D. Clerk and G. A. Burls, Vol. ii, 1913, and of course others).

The patent specifications of the period offer a wide field for research, fascinating when one is following the unfolding of a particular type, but too intricate for a Paper of this kind; in fact, very often they are like Gratiano's reasons:—"two grains of wheat hid in two bushels of chaff; you shall seek all day ere you find them; and when you have them they are not worth the search." For the designer, however, there is much interest in retracing the more important routes which had to be explored, in noting the ingenuity, rather than invention, exercised in steering clear of those blocked from time to time by prior patents, and, in the earlier years particularly, the inexperience of the experimenters and their want of imagination in realizing what might be attained.

The Author would have liked to trace these influences thoroughly, but he can only allude to some in passing; further, whilst the original intention of the Paper was to explore fully all that had been done in this county, even this he has been compelled to curtail, and to limit himself to the most important methods of vaporisation and ignition adopted, and to the increasing economy effected from time to time. Several names and variations are omitted consequently, and members will no doubt accept this explanation if the Paper falls short of what might be expected.

The first real development began with the engine made by Priestman Bros., of Hull, which was based on the Etève Patents, imported from France (1884), and became a practical motor when furnished with their own improvements of 1885–1892. It was exhibited at the Royal Agricultural Show at Nottingham in 1888, and as many difficulties had to be overcome the credit attached to its manufacture was well deserved.

In December 1891 a series of tests of a 5 h.p. engine by Professor Unwin showed a minimum comsumption of 0·842 lb. per b.h.p. hour of Royal Daylight Oil, 0·796 specific gravity and a thermal efficiency of 15·5 per cent.*

The engine was four cycle and the principle of working adopted

* Proc., Inst.C.E., vol. cix, 1892.

may be described as the use of an exhaust-gas heated vaporiser, separated from the engine cylinder, into which was sprayed, by an adjustable air-pressure, the jet of oil fuel, the main air for the charge being drawn with the mixture also through this vaporiser and the admission-valve by the suction of the piston.

The charge was compressed on the return stroke in the usual way and fired electrically; obviously the spraying of the oil and the proper proportioning of the air and the fuel oil required by the varying loads on the engine, were not easy problems, and involved delicate adjustments which were made more difficult by the unstable character of the charge contained in the detached reservoir and the length of the connecting passage to the cylinder.

In 1887 Knight commenced his series of devices for an engine for using "heavy hydro-carbons such as kerosene and paraffin lamp oils," in which again a vaporiser separated by a valve from the cylinder was used; there was no air-blast, and the chamber was heated at starting by a lamp, which afterwards could be more or less dispensed with.

In 1891 this form developed into what afterwards became known as the Trusty engine, in which the vaporiser was a jacket round the combustion-chamber and heat was imparted to its outer walls or through a chimney in the vaporiser, by the blow lamp at starting. Ignition was effected at first by an outside flame, burning constantly, but in the early Trusty engines the heat of the combustion-chamber walls was relied upon after starting, which in turn was supplemented by an ignition-tube or an internal igniter in the engines made in 1895 in Lincoln by Clayton and Shuttleworth, who then were licensees.

Other and simpler methods of working were being developed; in 1886 Akroyd Stuart and Binney devised means for "visibly measuring the combustible liquid and for mixing with the incoming air, also for vaporising both externally and in the cylinder." The engine was four-cycle and charge electrically fired, the fuel being of the spirit or petrol class. Other designs followed in 1888 and 1889, the last referring to heavy oil apparently, and providing a revolving series of blades to form fresh vaporising surfaces, relying on these evidently rather than on the heat of the charge. The

great advance, however, came in the year following in the two complementary inventions of Stuart.

Unlike most of the previous experimenters (the Spiel engine being an exception) Stuart, who had worked on the principle of forming a vapour mixture with the air charge (Patent No. 7,146), drew his air-charge into a vaporising chamber in open communication with the cylinder, into which the fuel was delivered by a pump at about the end of the compression-stroke, when the air was heated partly by the compression, partly by radiation from the highly-heated walls of the chamber and partly by the exhaust gases still remaining in the cylinder, the ignition being effected by the resulting temperature of the charge. This simple step was a distinct advance, in that pre-ignition of the charge, which hitherto had been a continual trouble, could be prevented by the correct timing of the fuel-injection, and further it made possible the use of higher compression pressures.

A few engines of 2, 4, and 6 b.h.p. were built at Bletchley using Shale oil and Russian oil of about 0·85 specific gravity. In 1891 Professor W. Robinson tested an engine developing 7·6 b.h.p. with a consumption of 1 lb. per b.h.p. hour, corresponding to an effective heat efficiency of about 13·5 per cent.

In the engine described in the second patent, No. 15,994, of 1890, the vaporising chamber was of similar form, in open communication with the cylinder by a narrow neck, the air being drawn, not through the chamber, but direct into the cylinder. Stress is laid both on this arrangement of air-inlet and on the narrow communication between the vaporising chamber and the cylinder. The previous patent was silent upon the latter point, its value, therefore, had probably not been appreciated. The oil was injected by a pump into the vaporiser during the suction stroke, and not at about the end of the compression stroke, in order that it might have a longer time to vaporise. At the close of the compression stroke the charge in the vaporiser was fired, as before, by the temperature of compression and the vaporiser walls. This gave automatic ignition, dispensing with the lamp (except for starting) and the heated tube or electric ignition used hitherto.

The first design of Akroyd engine, of 1890, had possibly given trouble, on account of the low temperature of the vaporiser and incomplete splitting up of the fuel. It is interesting to note, therefore, the change in the position of the air-valve in the later engine, which would increase the heat of the vaporiser. In a recent letter from Mr. Stuart to the editor of the *Motorship* he states:—

"Little experience had been gained by the laymen at that early period regarding the working of oil-engines, and this Akroyd engine cycle, patent No. 15,994, October 8th 1890, was developed to fill the then requirements of a comparatively low compression simple engine. These engines were very reliable and easily managed."

In June, 1891, the sole right to manufacture the Stuart engines under licence for the whole world was acquired by Richard Hornsby and Sons, Grantham, and it was mutually agreed that the type in conformity with patent No. 15,994 should be built and sold as the "Hornsby-Akroyd" oil-engine.

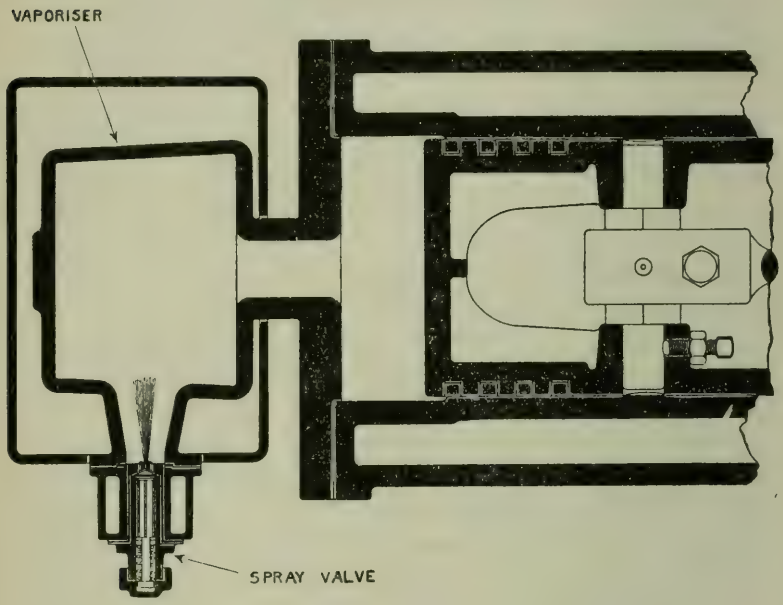
In February 1892, Mr. Akroyd Stuart took out patent No. 3,909, for a vaporiser fitted in part with a water-jacket to regulate its temperature, as it had been found that the vaporiser became overheated after prolonged running on full load, and this the partial water-jacket could overcome.

A series of tests was made upon a Hornsby-Akroyd engine by Professor Robinson in October and November 1893, using "Russoline" oil of 0·824 specific gravity, and net calorific value of 18,600 B.Th.U. At full working load of just under 5 b.h.p., the average consumption was 0·99 lb. per b.h.p. hour, equivalent to an effective thermal efficiency of about 14 per cent. The compression pressure was about 40 lb. per square inch, with a mean brake effective pressure of 26·4 lb. per square inch, and a maximum pressure of 100 lb. per square inch.

Fig. 1 (page 678) shows a sectional view of the engine as designed in 1891, and Fig. 2 the 1896 design in which part of the vaporiser is water-jacketed, and there is a separate hot cap, thus allowing the heat to be proportioned to suit the different grades of fuel. The second illustration is representative of the engines as built at the present day, up to 66 b.h.p., for using refined, crude or refuse oils.

Fig. 3 (page 680) gives typical indicator diagrams of both types, also of a later engine which will be described presently. It will be noticed that in the 1896 design, owing to the partial water-jacketing of the vaporiser, it was possible to raise the compression pressure from 40 lb. per square inch to 65 lb. per square inch, whilst the mean brake effective pressure was raised from 26·4 lb. per square

FIG. 1.—1891 *Type*.
R. Hornsby and Sons, Grantham.



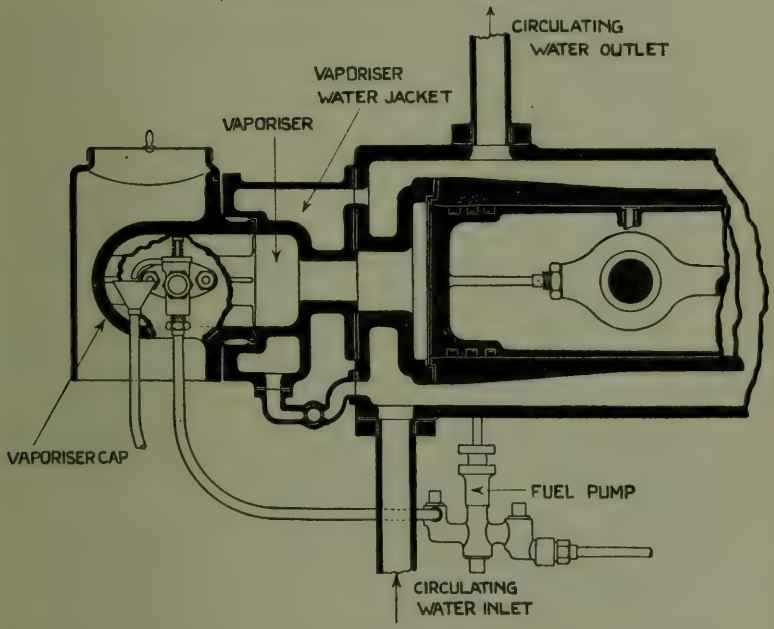
inch to 35 lb. per square inch at the working load of the engine; the effective thermal efficiency increased to 18 per cent.

Thus originated an oil-engine, which may be said to have achieved a wider reputation than any for simplicity, reliability and general usefulness.

Diesel patented his first engine in 1892, and, although this is not directly connected with the manufacture of oil-engines in Lincolnshire, it is desirable to refer to his specification to show the position of his engine relative to present developments.

The essential difference between the Diesel Engine and the Stuart Engine of 1890 lay in carrying the compression pressure much higher, in order that the resulting temperature should well exceed that of the igniting point of the fuel; in fact, Diesel seems in his specification to lay so much stress on this claim that the essentials of a practical engine are lost sight of. Pulverized coal was to be the fuel, admitted at about the end of the compression

FIG. 2.—1896 *Type*.
R. Hornsby and Sons, Grantham.

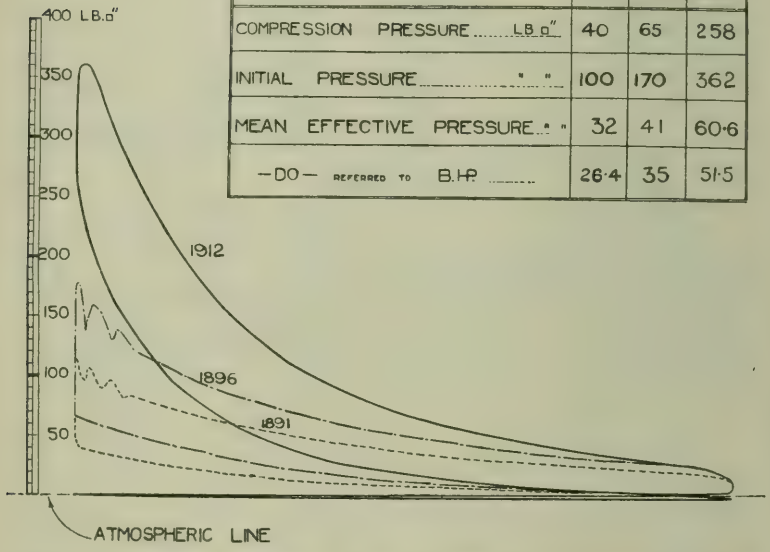


stroke, and, according to Diesel, the combustion was to proceed gradually under constant pressure so that the diagram should have "a flat top," by the exact adjustment of the entering charge, and governing was to be effected by cutting off the fuel supply according to the load upon the engine. The use of liquid fuel was also contemplated, which was to be forced into the cylinder by means of a pump having a cushion of compressed air, at a pressure

exceeding the compression pressure. It should be carefully noted there was no injection air with the charge; this principle was patented in 1895. He stated that "in the new process the highest pressure and the highest temperature are produced essentially not by combustion, but by mechanical compression. The combustion itself, in opposition to all hitherto known processes of combustion, does not produce any increase of temperature, or at least

FIG. 3.—*Typical Indicator Diagrams.*
R. Hornsby and Sons, Grantham.

TYPE OF ENGINE	1891	1896	1912
COMPRESSION PRESSURE ..... LB. □"	40	65	258
INITIAL PRESSURE ..... " "	100	170	362
MEAN EFFECTIVE PRESSURE " "	32	41	60·6
—DO— REFERRED TO B.H.P.	26·4	35	51·5

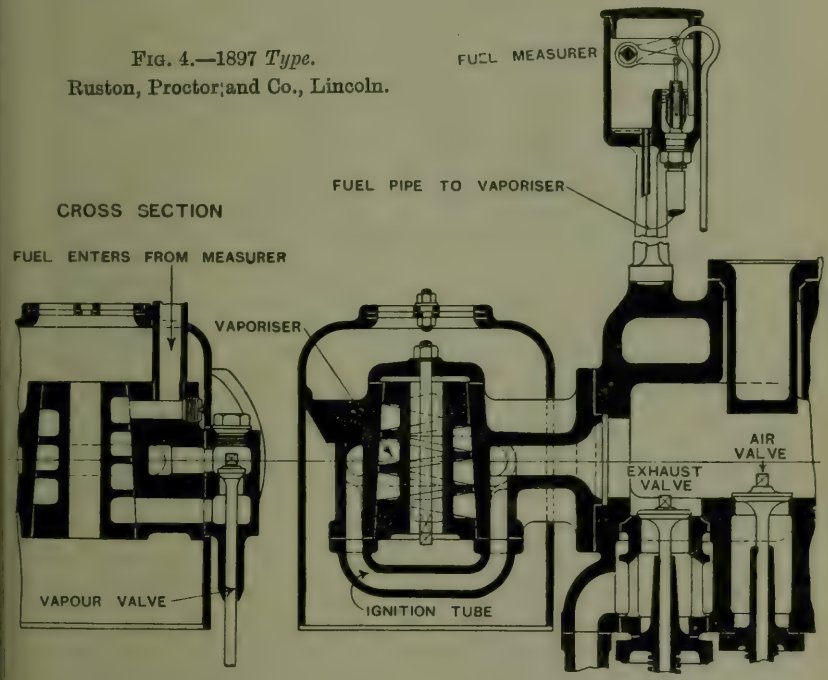


only an unessential one; the highest temperature (in the cylinder) is produced by the compression of air; it is, therefore, under control and will be kept correspondingly in moderate limits; as moreover the subsequent expansion cools the body of gas to a very high degree, it is obvious that no artificial cooling of the cylinder walls is necessary." There was, therefore, no water-jacket to the cylinder, nor any special lubrication, for he says, "The mean temperature of the cylinder contents necessary for

keeping the parts tight and lubricated, and in general for the practical working of the engine, is obtained solely by the process itself, whereby also it differs from all known processes."

It, no doubt, did differ, and to those who have struggled with overheated cylinders, cracked pistons and lubrication worries, it will not be surprising that the engine was a source of continual trouble, and made no headway until its impracticable features had

FIG. 4.—1897 *Type*.
Ruston, Proctor and Co., Lincoln.



been eliminated. In passing, it might be mentioned that in the old firegun, tinder was ignited by the heat produced by the sharp compression of air by a piston.

The foregoing remarks outline the position of the oil engine in the early "nineties," and little further advancement appears to have taken place until about the year 1904 when the Akroyd-Stuart patents of 1890 expired. Oil engines built in the county

during the intervening time were improved in detail and became reliable power agents. Thermally, however, the advance was small.

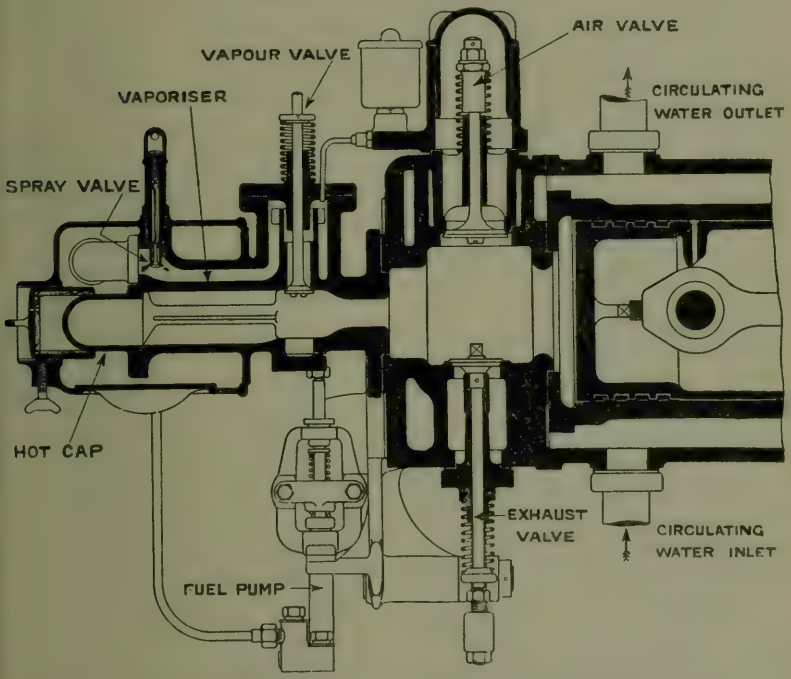
The Stuart patents precluded other manufacturers from the use of a vaporiser communicating by an open neck with the working cylinder, and this was a vital point. It was necessary, therefore, to develop the engines on the lines of an external vaporiser communicating with the cylinder by a valve, such as had been done prior to 1890, and, although considerable ingenuity was shown in the devices employed to overcome the difficulty of automatically heating the vaporiser just enough for light running and yet not too much when on full load, some hand adjustment was the rule. Fig. 4 is representative of an engine of this type built in Lincoln first in 1897, ranging in sizes up to 50 b.h.p. working load with refined petroleum. In this the fuel oil was delivered by a measurer into a spirally shaped vaporiser situated in and heated by a loop in an extension of the combustion-chamber; some air was drawn into the vaporiser with the fuel, and the mixture was admitted to the combustion-chamber by a vapour-valve opened more or less simultaneously with the main air-valve of the cylinder.

The combined charge was compressed in the usual way, and fired by a by-pass or U-shaped tube kept at a much hotter temperature than the vaporiser or combustion-chamber (by the heat of the successive explosions) because of its being made of thinner metal and the asbestos insulation in the joints at each end. This design was simplified subsequently as to the vaporiser and an internal ignition-tube was added.

The measurer was replaced by a fuel pump. Fig. 5 shows a later design of 1906 in which the general principle remains the same, but the vaporiser was in the form of a dish heated by an extension of the combustion-chamber. The fuel was split up by being driven by the pump through a nozzle furnished with a spring-loaded valve. Ignition was effected by a hot cap. A water drip was added to control the heat. By suitably proportioning the areas of the vaporiser and the extension of the combustion chamber, and in particular the thickness of their walls, crude oil could be used as fuel, and the engine had an extended sale.

It could not use, however, refuse oils, and required some adjusting when passing from full to light load or *vice versa*. Engines of this design were built in sizes up to 70 b.h.p. working load with a compression of about 45 lb. per square inch. The consumption of the larger engines was 0·55 lb. and 0·75 lb. per

FIG. 5.—1906 *Type*.
Ruston, Proctor and Co., Lincoln.



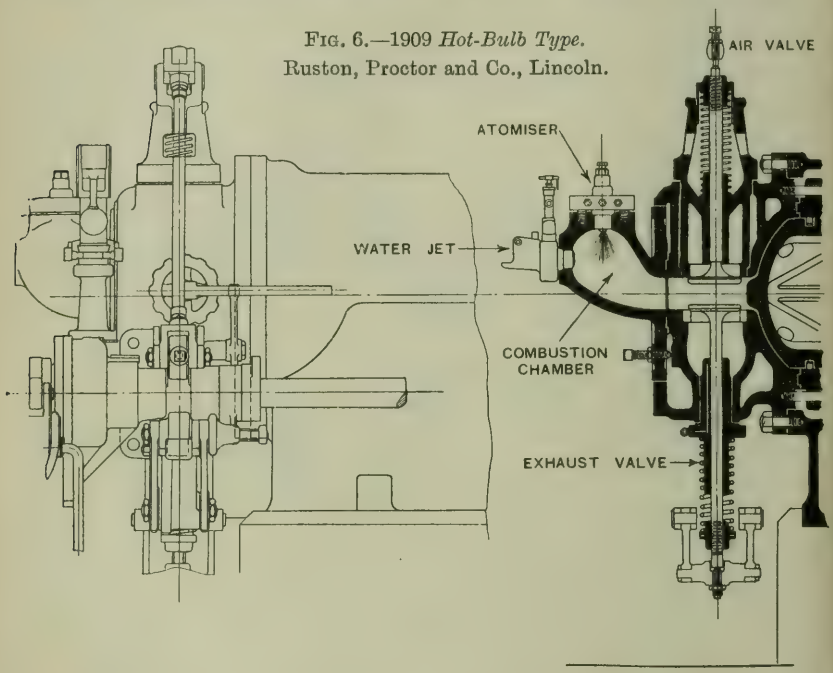
b.h.p. hour on refined and crude oils respectively, equivalent to thermal efficiencies of 25 per cent and 18 per cent.

Another engine, differing somewhat in detail but akin, was built at Stamford in 1894, that is to say it was of the external vaporiser type, the vaporiser being heated by the temperature of the explosion, much on the lines of the Trusty engine already alluded to, and in performance it appears to have been similar.

On the expiry of the two Stuart patents in 1904 and the earlier

Diesel patent of 1906, the way was open to designers to develop engines on the lines of either; possibly weak points in these patents could have been found, if bold action had been taken earlier; anyway, after these dates many new engines appeared. One of the most successful was developed by Ruston, Proctor and Co. in 1909, Fig. 6, having a compression of 280 lb. per square inch, in which the

FIG. 6.—1909 *Hot-Bulb Type.*
Ruston, Proctor and Co., Lincoln.



fuel was injected directly into the air compressed in a hot-bulb combustion-chamber at about the end of the compression stroke. This bulb was not water-jacketed, but its temperature was regulated by water injection, the amount of water required being about 0·2 lb. per b.h.p. hour, which with a small amount of air entered into it as vapour. A choke or neck was placed between the combustion-chamber and the cylinder head, and the fuel charge was injected into the compressed-air charge, by the direct action of a fuel-pump driving the oil through an atomiser.

This atomiser was essential to the engine, as on its action depended the efficiency obtained. It was copied in various directions. The fuel consumption obtained with this engine showed a marked improvement, as evidenced by the tests made by Professor Robinson in 1910.

Extract of Professor Robinson's Report on Test made on a 050 *"C.C." Class. "O." Engine, which was in every respect a Standard Engine:—*

	Oil used:— Russian crude.	Italian refuse.	
Load	Full	Full	¾
Duration of trial	2 hours	2 hours	1 hour
Mean revolutions per minute	205·7	205·5	208·8
Net load on brake (mean) lb.	350	346	257·9
Brake horse-power	51·8	50·8	38·5
Oil used per hour (lb. weight)	23·25	24·9	18
Oil used per b.h.p. hour (lb.)	0·45	0·49	0·47
Thermal efficiency:—			
Calorific value of 1 lb. oil per cent	100	100	100
Heat equivalent of work done in cylinder, per cent on i.h.p.	40·4	37·5	41·6
Effective thermal efficiency, b.h.p.	31·4	29·5	30·8

During the test, samples of oils were taken, which gave the following values:—

	Russian crude.	Italian refuse.
Specific gravity at 60° F.	0·875	0·947
Higher calorific value B.Th.U. per lb.	19,100	18,620
Latent heat of steam formed by hydrogen	1,100	1,020
Lower or effective heating value of 1 lb. weight oil in B.Th.U.	18,000	17,600

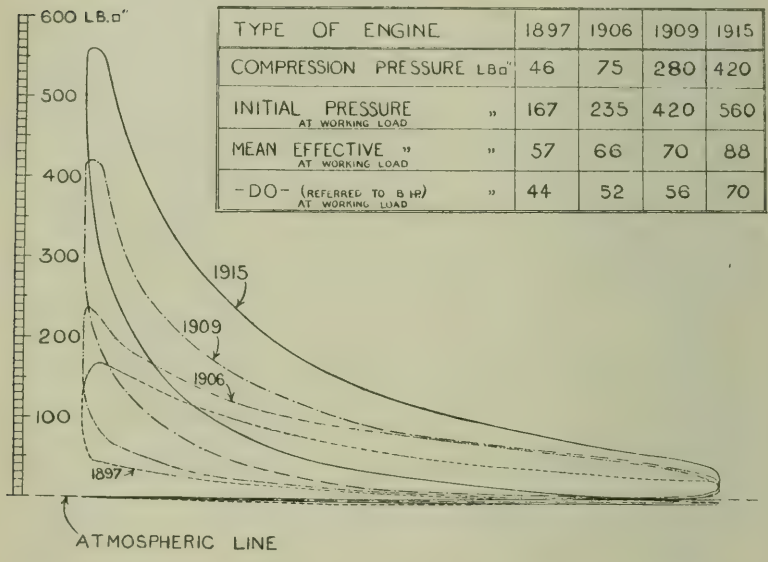
This particular engine had been run for some time, but an average figure for engines of 50 b.h.p. and upwards is about 0·5 lb. per b.h.p. hour, with fuel of 18,000 B.Th.U. per lb., giving a thermal efficiency of about 28 per cent. The M.E.P.* at working load was about 56 lb. per square inch, an improvement of about 4 lb. over their engine of 1906. Fig. 7 (page 686) shows the comparative diagrams.

* Corresponding to the brake horse-power.

In 1908 the Grantham firm introduced an engine having a compression of 180 lb. and a sealing valve which shut off the vaporiser from the air and exhaust passages during the compression and explosion strokes; otherwise it was of the hot-bulb type with the fuel sprayed into the compressed charge. Particulars of a test are given in the Table at the end.

This was followed in 1912 by their two-valve "R" type engine,

FIG. 7.—*Comparative Indicator Diagrams.*
Ruston, Proctor and Co., Lincoln.



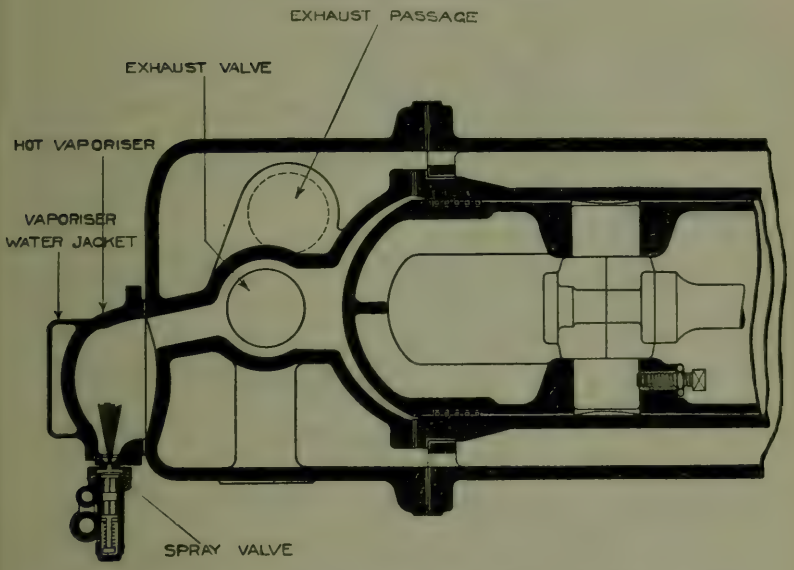
TYPE OF ENGINE	1897	1906	1909	1915
COMPRESSION PRESSURE LB□"	46	75	280	420
INITIAL PRESSURE " AT WORKING LOAD	167	235	420	560
MEAN EFFECTIVE " " AT WORKING LOAD	57	66	70	88
-DO- (REFERRED TO B.HP.) " AT WORKING LOAD	44	52	56	70

Figs. 8 and 9 (pages 687–8), in which the compression pressure was increased to 250 lb. per square inch. This again was a reversion to the first Stuart patent as regards compressing the air-charge without the admixture of the fuel until the compression was complete, but there was added the partially cooled vaporiser and an inclined passage to the cylinder into and against the wall of which the fuel was injected by the pump through a carefully proportioned nozzle. The liquid was thus finely sprayed and intimately mixed with already compressed air-charge in a chamber which could be

regulated as to its temperature by the partial water-jacket. Ignition commences in the unjacketed portion, which is heated by a lamp before starting the engine.

An official test made upon a 320 b.h.p. two-cylinder engine using Texas Liquid Fuel of 0·9 specific gravity and 18,875 B.Th.U. gave a consumption of 0·47 lb. per b.h.p.-hour, equivalent to an efficiency of 29 per cent, and a mean brake effective pressure of

FIG. 8.—1912 *Type* "*R.*"
R. Hornsby and Sons, Grantham.

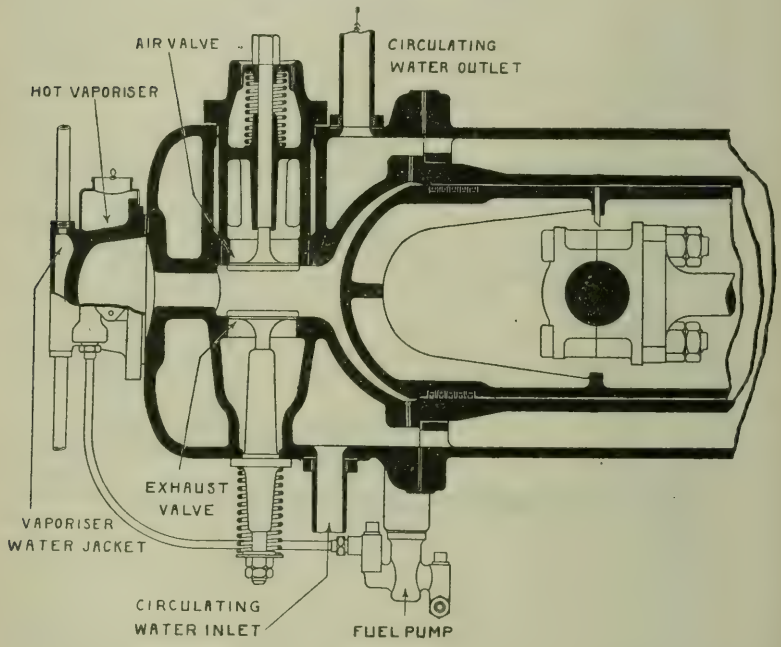


51·6 lb. Fig. 3 (page 680) shows a typical indicator diagram from one of these engines and how it compares with the diagrams from previous engines of the same makers. This type is now built in sizes up to 170 b.h.p. per cylinder, making an engine of 340 b.h.p. working load, when coupled.

Another design of engine was developed at about this time at Stamford, having a compression pressure of 150 lb. per square inch for the main charge, and a more highly compressed-air injection for the fuel, for which purpose a horizontal air-pump

attached to the engine-bed was driven from the crank-shaft. A small hot-bulb started automatically the ignition of a supplementary spray which ignited in turn the spray of the main charge; and a lamp was required for starting. Trials made at Gloucester in 1909, show a consumption of 0·58 lb. per b.h.p.-hour, when using Texas Crude, which is equal to a thermal efficiency of about 24 per cent.

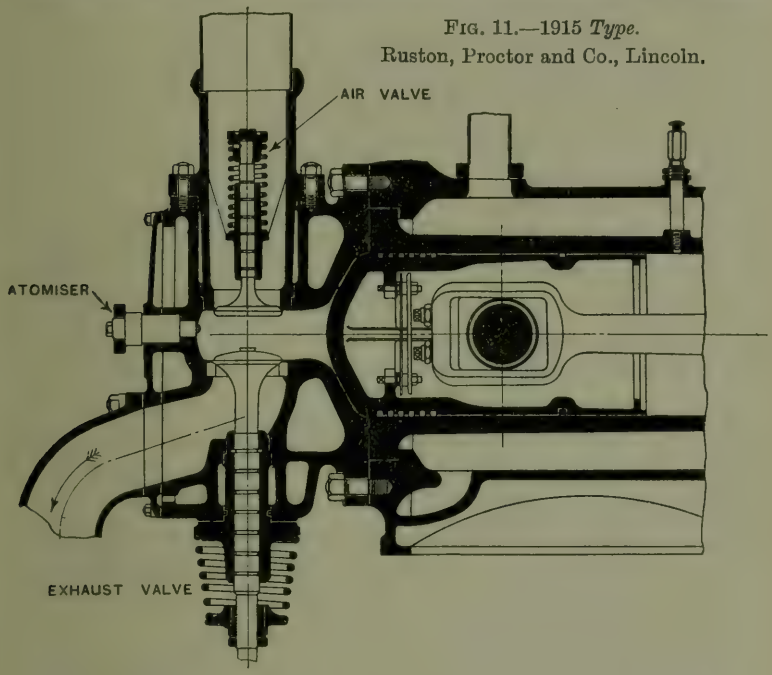
FIG. 9.—1912 *Type* "*R.*"
R. Hornsby and Sons, Grantham.



Although the engines just described show a marked advance upon their predecessors, the thermal efficiency was still lower than the best, as exemplified by the Diesel engine with a brake efficiency of about 35 per cent; further, they required a lamp for starting, or adjustments were necessary to maintain the heat balance of the engine at varying loads, or they were limited as regards the grade of fuel oil which could be used.

With the knowledge of the efficiency which could be obtained by higher compression and more perfectly atomising the fuel, a further step was taken by Ruston, Proctor and Co., and in 1912 experiments were begun, and data obtained by which an engine was designed in 1913, which gave remarkably good results and is still in regular

FIG. 11.—1915 *Type*.
Ruston, Proctor and Co., Lincoln.



service. It developed 25 b.h.p. with a consumption of 0·48 lb. of average fuel-oil per b.h.p. per hour.

This was the forerunner of a series, Fig. 10, Plate 7, of which Fig. 11 shows a section. It starts from cold, without the use of a lamp, by compressed air of from 200 to 300 lb. per square inch, stored in a receiver, with a drop usually of about 60 lb. per square inch; no adjustment is required of the temperature of the hot bulb or vaporiser, for there is none, and it is practically indifferent as to the grade of fuel oils which it has to use.

For tar oils a pilot ignition is fitted, which can then be used

as readily as an ordinary fuel-oil; the consumption of pilot oil is about 5 per cent of the tar oil used at the rated working load.

Although the working pressure has been increased, the wear of the major moving parts promises to be lessened, for as the thermal efficiency improves, temperatures appear to be better distributed and more manageable.

As regards increase in compression, this obviously depends on the ignition point of the fuel which is to be used, and in the Diesel engine it is from 450 lb. to 500 lb. per square inch. Supino, in his book of 1913, mentions 29 atmospheres, and Sabathé in 1912 states 28 metric atmospheres (398 lb. per square inch) as sufficient to get the required combustion, whilst experiments on a small Diesel engine at the Birmingham University,* in which special arrangements were made to vary the compression, included compression pressures as low as 300 lb. per square inch for petrol.

When oil fuel is pulverized by compressed air in the usual way, there is a cooling effect, as the air expands from the receiver pressure down to the pressure of the compressed charge in the cylinder. Thirty atmospheres has been adopted in the new engine as a sufficient compression pressure for any fuel oil. The atomising is effected by forcibly compelling the liquid to lift its own spring-loaded needle-valve which closes the opening to the injection nozzle, by the motion of a steep cam actuating the fuel pump plunger, as in the 1909 engine.

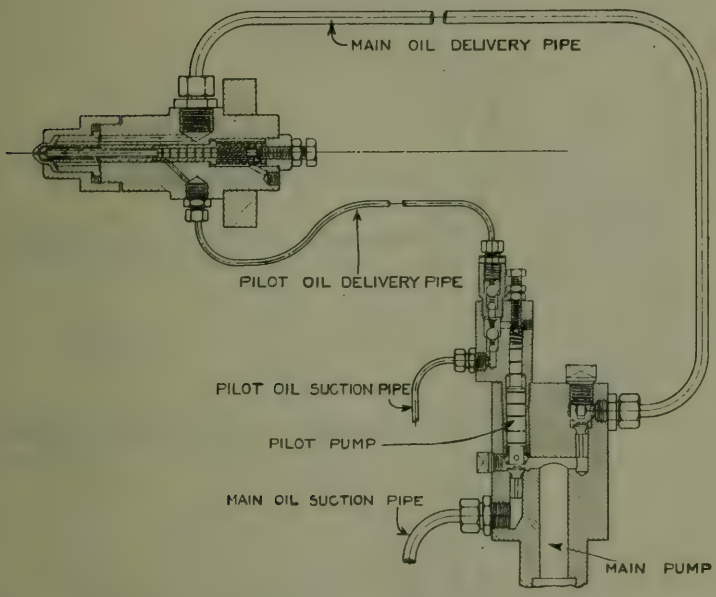
With pilot ignition the pilot oil is discharged by a needle-valve inside the main needle-valve, which is tubular. The pilot oil-pump is actuated by the impulse of the fluid on a stepped plunger in the main fuel pump, so that perfect precedence is secured for the igniting jet. The construction is shown in Fig. 12.

These engines are made up to a horse-power of 170 in a single cylinder, and the consumption of fuel oil ranges from 0·48 for 20 b.h.p. down to 0·4 lb. per b.h.p. per hour for the largest size, this being obtained with a fuel oil of 0·92 sp. gr. and not less than 18,000 B.Th.U. per lb., and is equivalent to a thermal efficiency of 30 to 35 per cent.

* Proceedings, Inst. C.E., vol. clxxix, 1910.

Finally, it can be claimed for this engine that it works with the same brake economy as the Diesel engine, without the complication of the two-stage air-compressor for injecting the fuel; further, it is not possible for the kind of accident to happen to it which has on certain occasions wrecked Diesel engines, namely, the leakage or sticking up of the fuel-valve, causing compression to

FIG. 12.—*Pilot Oil-Pump and Atomiser.*
Ruston and Hornsby.



commence above atmospheric pressure, and pre-ignition, thereby producing an explosive pressure of twice or more the proper maximum.

The Author wishes to thank Mr. Oswald Wans, who has been associated with him and has been responsible for the development of the engine, for his valuable assistance in preparing this Paper, and Mr. James, whose long and intimate knowledge of the Grantham practice has been available.

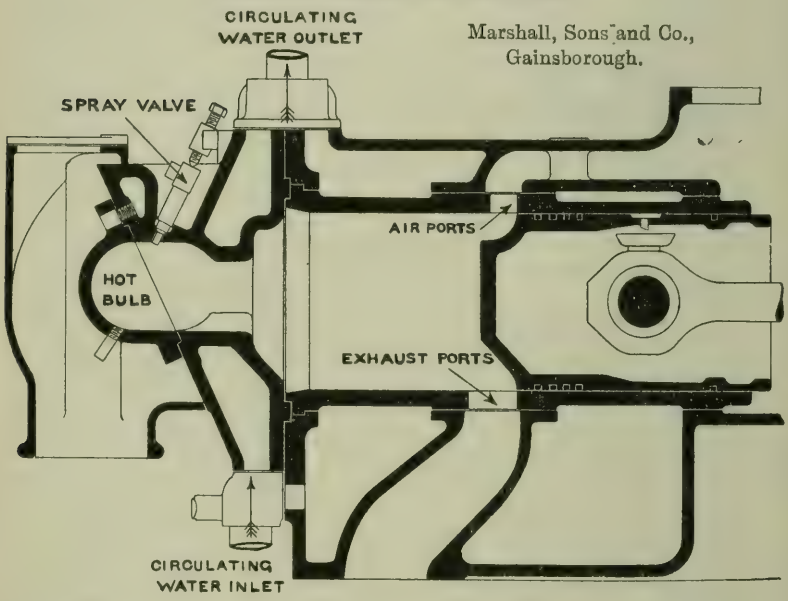
Before closing, there is another type of oil-engine which is

a class to itself, namely, the two-stroke hot-bulb. Of these, illustrations of two examples are given, by courtesy of the makers.

Fig. 13 illustrates a section of a horizontal engine by Marshall, Sons and Co., of Gainsborough, in which the fuel is injected into a partially water-jacketed hot-bulb, heated by a lamp to start. A similar type of engine is also constructed by Clayton and Shuttleworth, of Lincoln.

Fig. 14 is a section of a vertical engine also of the same type

FIG. 13.—*Two-stroke Hot-Bulb Type.*

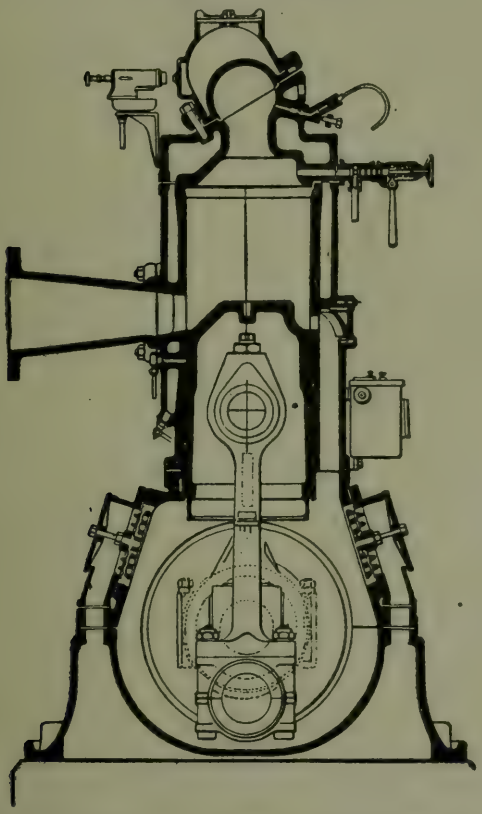


made by Robey and Co., of Lincoln, in which the usual difficulty of the automatic adaptation of the hot-bulb temperature, the Author is informed, has been overcome.

Two-cycle engines, being without an exhaust-valve and half-time shaft, have fewer parts as well as the advantage of an impulse each revolution; on the other hand, it is impossible to get in the piston the same mean effective pressure (as in the four-cycle) seeing that on the return stroke not only have the spent gases to be

exhausted, but the fresh charge of air has to be taken in and compressed; which is delivered at a pressure of a few pounds from the crank-case. The increasing use of this type indicates a growing

FIG. 14.—*Two-stroke Hot-Bulb Type. Sectional side elevation.*
Robey and Co., Lincoln.



appreciation of its value. A Table is appended (pages 694–5) showing the progressive efficiencies obtained by the engines described.

Summing up, the Author has endeavoured, in describing the types put forward, to trace the steps by which the present-day designs have been reached, to show the connexion of these with

Table showing the Development

Year of Trial.	B.H.P.	Consumption lb. per B.H.P. hour.	Effective Thermal Efficiency per cent.	Authority.	Compression Pressure lb. per sq. inch.	M.E.P. lb. per sq. in. indicated.	Vaporiser Connection to Cylinder.
1891	7·6	1·0	13·5	Professor Robinson			By open neck
1893	5	0·99	14	Professor Robinson	40	31·8	By open neck
1898	8	0·73	19	Makers	40	43	By passage and valve
1899	25	0·74	18	Professor Robinson	60	40·75	By open neck
1901	12	0·73	19	Cardiff Trial	40	42	By passage and valve
1906	85	0·78	18	Makers	45	49	By passage and valve
1908	77	0·6	22·4	Makers	180	60	By open neck
1910	51	0·45	31	Robinson	280	78	By open neck
1913	300	0·47	28·7	E. Calvert Finchley, U.D.C.	265	61·5	By open neck
1914	25	0·48	30	Makers	420	80	None
1920	120	0·4	35	Makers	430	85	None
*1920	16	0·58	22·9	Makers	150	—	By open neck
*1919	51	0·51	27·7	British Engine, B. & Elec. Insce. Co.	—	—	By open neck

* These engines are of the

of the Oil-Engine in Lincolnshire.

Method of Injection.	Method of Ignition.	Heat of Vaporiser Controlled by	Method of Starting.	Fuels used.	Manufacturer.
At the end of Compression	By Hot Vaporiser	None	Lamp	Refined	Akroyd Stuart, Bletchley
During Suction Stroke	By Hot Vaporiser	None	Lamp	Russoline	R. Hornsby and Sons, Grantham 1891 Type
During Suction Stroke	By Hot "U" Tube	None	Lamp	Refined	Ruston, Proctor and Co. 1897 Type
During Suction Stroke	By Hot Cap	Partial Water-Jacket	Lamp	Russoline	R. Hornsby and Sons, Grantham 1896 Type
During Suction Stroke	By Hot Tube	Water Drip	Lamp	Refined	Ruston, Proctor and Co.
During Suction Stroke	By Hot Tube	Water Drip	Lamp	Crude Oil	Ruston, Proctor and Co. 1906 Type
At the end of Compression Stroke	By Hot Cap	Partial Water-Jacket	Lamp	Borneo Liquid Fuel	R. Hornsby and Sons, Grantham 1908 Type
At the end of Compression Stroke	By Hot Vaporiser	Water Drip	Lamp	Russian Crude	Ruston, Proctor and Co. 1909 Type
At the end of Compression Stroke	By Hot Cap	Partial Water-Jacket	Lamp	Texas Liquid Fuel	R. Hornsby and Sons, Grantham 1912 Type
At the end of Compression Stroke	Heat of Compressed Charge	None	From cold	Fuel oils of not less than 18,000 B.Th.U.	Ruston, Proctor and Co.
At the end of Compression Stroke	Heat of Compressed Charge	None	From cold	Fuel oils of not less than 18,000 B.Th.U.	Ruston, Proctor and Co. 1915 Type
At the end of Compression Stroke	By Hot Cap	Partial Water-Jacket	Lamp	Gasoleum	Marshall, Sons and Co., Gainsborough
At the end of Compression Stroke	By Hot Cap	Partial Water-Jacket	Lamp	Anglo-American Fuel Oil	Robey and Co., Lincoln

two-stroke cycle type.

each other, and the influence of one invention on its successor, sometimes helping, at other times compelling a departure in another direction.

An immense amount of hard thought has been brought to bear on the problems involved, which, although they seem simple, are so complex that it can be said truly that, unless this thought had been accompanied continually by patient testing and comparison of results, progress would not have been effected.

This description has been limited to some only of the engines made in this county, and mainly to those of which the Author has the fuller knowledge; but simultaneously developments of the four-cycle engine have taken place elsewhere in this country, on the Continent and in America, whilst the two-cycle type has been made very extensively abroad.

The tendency to-day is to save time and labour, so that starting devices will be demanded increasingly—for instance, the 1906 pattern engine described has been fitted successfully with an electrically-heated vaporiser and electric ignition, and could in a few minutes be started by moving a switch only.

Even this interval, however, may be eliminated; there are paraffin engines which can be started on petrol like a motor car; the larger engines of the 1915 type start from cold by compressed air, as already described; and another device consists of a spray electrically ignited, and compressed air.

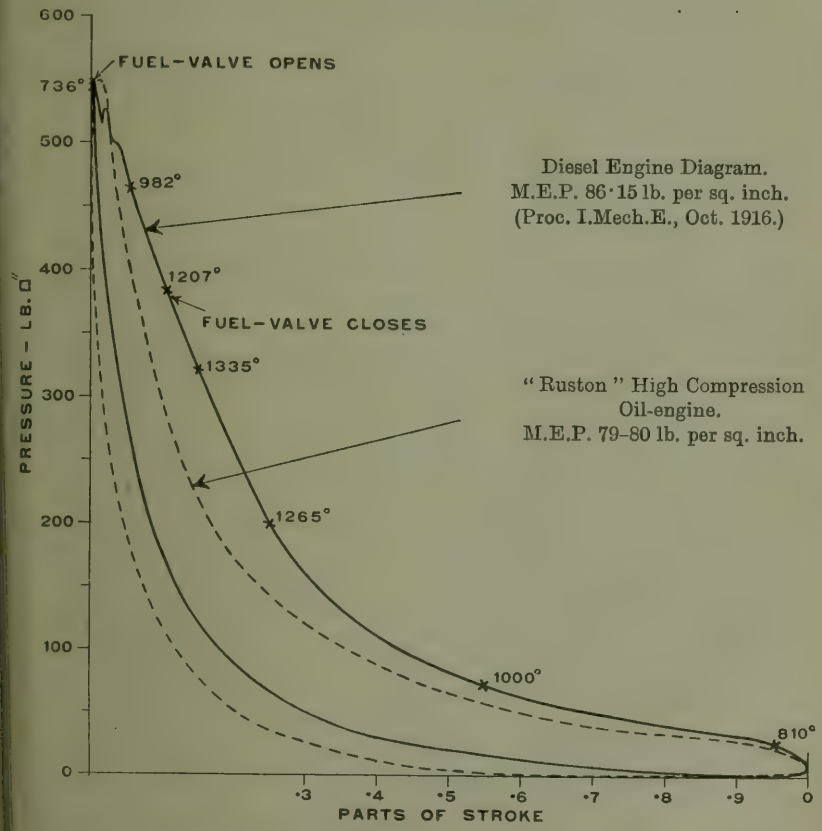
Whilst the oil-engine has increased in thermal efficiency during the period under review, it has gained in reliability and convenience to the user, and mechanically its advance has been still more important.

The Paper is illustrated by Fig. 10, Plate 7, and 13 Figs. in the letterpress.

Discussion.

Mr. F. H. LIVENS showed a series of lantern slides illustrative of the engines referred to in the Paper. Among them was Fig. 15, which showed the comparison of the Diesel engine diagram taken

FIG. 15.—*Comparative Diagrams.*



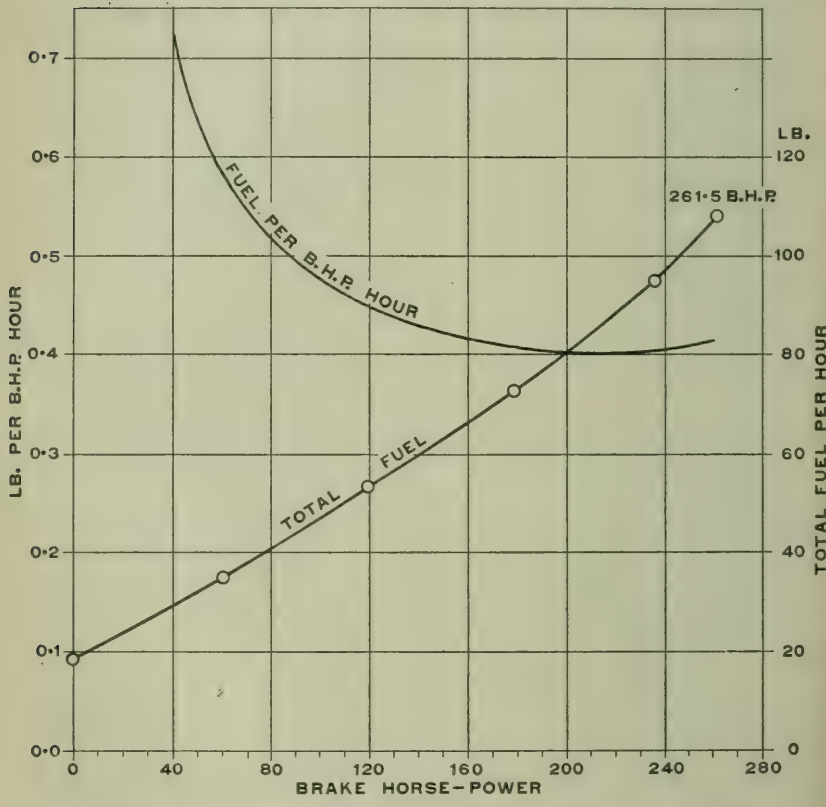
from page 594 of the Proceedings of this Institution, October 1916, with a diagram from the high-compression oil-engine of the Ruston 1915 type of the same initial pressure and very nearly the same mean effective pressure. The compression pressure on the Diesel

(Mr. F. H. Livens.)

engine diagram was about 550 lb., on the Ruston engine diagram 430 lb. per square inch, and the temperatures marked on the former showed a rise of 600° C. above that existing when the fuel-valve opened, which proved that the claim of Diesel for combustion without

FIG. 16.—*Fuel Consumption Curves.*

Twin High Compression Oil-engine, R.P.M. 175. Ruston and Hornsby. Tests made 13th July 1920. Anglo-American Fuel Oil. Lower Cal. value 18,050 B.Th.U.

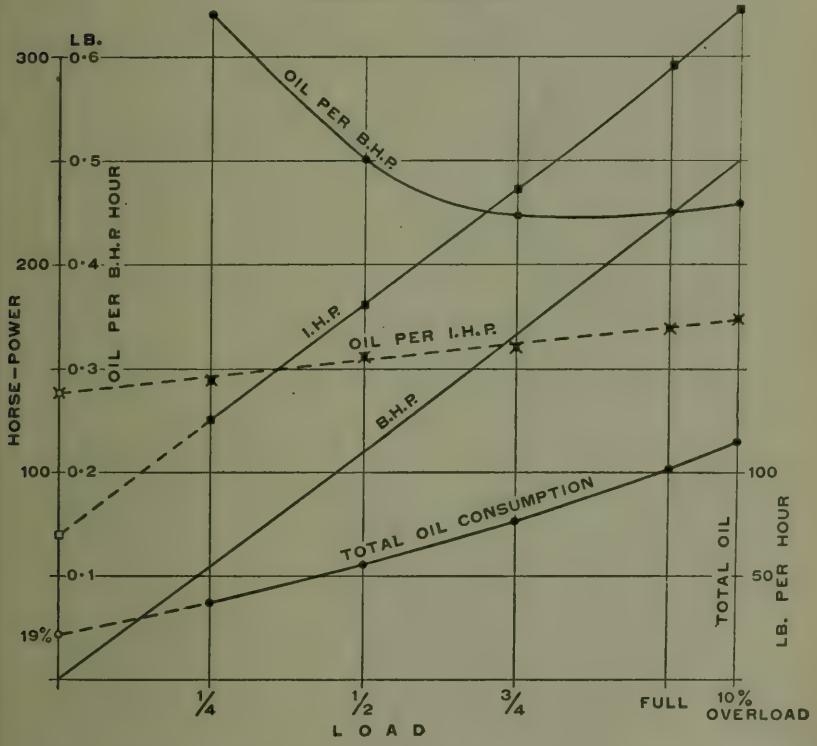


rise in temperature was entirely erroneous; further, it would be noted that the expansion line of the Ruston diagram took a lower course with, in all probability, lower temperatures.

The PRESIDENT showed a lantern slide, Fig. 16, relating to an

engine of the 1915 type, shown in Fig. 17, Plate 7, and described on page 690 of the Paper, which he had tested the previous week. The engine had two side-by-side cylinders each developing 130 b.h.p. at full load, and for the test it was started at 8 a.m. and ran most perfectly, without stopping, until 6 p.m. It was quite

FIG. 18.—*Test of Three-throw Diesel Engine. Willans and Robinson.*
B.H.P. 225. R.P.M. 196.



impossible to say by the sound what load was on the engine or when the load was changed.

The total oil consumption per hour was shown on the lower curve, Fig. 16, for over load, full load, three-quarter load, half load, quarter load, and no load. On plotting the test results, it was found that the three points relating to three-quarter, half

(The President.)

and quarter load were almost exactly in a straight line following the Willans Law. The points for full and over load were slightly higher than the line, and so was the point for the no-load test. He recommended this method of plotting because it was easy to draw a fair line with considerable accuracy, since the points lay nearly in a straight line. The upper curve had been determined from the lower curve and gave the fuel consumption per b.h.p. It would be observed that at somewhat less than the full load, namely, at about 220 b.h.p., the best economy was obtained, which was the remarkable figure of 0·4 lb. per b.h.p.-hour, and confirmed the statement in the Paper (page 690 and 1915 type in the Table). The fuel used was a thick, treacly Anglo-American oil, the calorific value of which had not yet been determined, but he presumed it would be somewhere in the neighbourhood of 18,000 or 18,100 B.Th.U. per lb.*

Fig. 18 represented a test he made about twelve years ago on a Willans-Diesel engine. It would be seen that the shape of the total oil-consumption curve agreed exactly with that in the previous figure. The best economy was about 0·45 lb. per b.h.p.-hour, that is, 0·05 lb. greater consumption than with the Ruston-Hornsby engine. Some little time ago he expressed the opinion that in due time the so-called Diesel engine would be replaced by an engine similar to the Ruston type, and he thought his prophecy was coming true.

The PRESIDENT said his first duty was to ask the members to pass a hearty vote of thanks to the Author for his most interesting Paper. It was an account of some Lincolnshire Oil-Engines, in particular those made by Messrs. Ruston and Hornsby, but in large measure it was the history of the oil-engine in this country. One of the slides which the Author had exhibited gave indicator diagrams taken at different dates and showed that increase of compression resulted in increase in economy, thus affording a

* Since determined at 18,050 B.Th.U. per lb. (lower value).

practical proof of the well-known theorem that as the compression increased so the thermal efficiency of the engine increased. Fig. 1 (page 678) gave the section of an engine working on the Akroyd cycle, the distinguishing feature of which was compression of pure air and admission of oil at the end of the compression stroke. That was precisely what the Diesel engine did, and therefore in his view the Diesel engine ought to be called the Akroyd engine. As a matter of fact, the patent which Diesel took out was, as the Author had very clearly shown, based on an impossible thermodynamic cycle. It was quite impossible for a gas to expand at constant pressure and at constant temperature at the same time; that could easily be proved beyond doubt. As a matter of fact, what was known as a Diesel engine at the present time was not the engine that Diesel invented. He thought the Institution might very well agree that an oil-engine compressing pure air and injecting oil at the end of the compression stroke should be called an Akroyd engine and not a Diesel engine. Mr. Pendred knew a good deal about that particular point, and as he proposed to ask him to join in the discussion, he would say nothing further on the matter himself.

The resolution of thanks was carried by acclamation.

Mr. W. A. TOOKEY thought he would be following the wishes of the majority of the members if in the first place he re-echoed the words that had fallen from the President in thanking the Author for what was an exceptionally good Paper. Very few Papers on oil-engines had been read before the Institution, and he hoped the present one would be the forerunner of many, for the oil-engine was a subject on which several Papers could easily be written, in view of the fact that a number of problems connected with it had yet to be solved. Some of the problems had already been surmounted in a very clever way, and he believed it would be possible in the future to learn the more quickly from past history and experiment as a result of discussion on such papers as had been presented by Mr. Livens.

The Author touched very lightly upon the improvements that

(Mr. W. A. Tookey.)

had been made year by year, but he had shown some diagrams which indicated very clearly the effect of those improvements. He had not said a word about the difficulties which had been experienced, but those who were familiar with oil-engine practice knew that they had been very troublesome indeed. The old type of oil-engine, in which it was necessary first of all to vaporise the oil before its admission to the combustion chamber, was an engine which, while it had proved to be of service in the hands of even unskilled men in factories, industrial works and private house-lighting plants, yet had its defects. He remembered well that in the early days it was quite usual to receive a telegram from a man who was running an oil-engine, asking that some one should be sent down because the engine would not operate, and it was then nearly always found that the only thing it was necessary to do was to clean the vaporiser and the exhaust box, which had become "sooted-up" with carbon, proving that the combustion of the majority of previous charges had not been complete. All those defects had, he thought, been overcome in the new designs, especially the latest design to which the Author had referred and of which the President had recently made a test. He had himself made a similar test on an engine of that description and was greatly surprised to find that, although that particular engine before his visit had not been at work for a whole week, it started up on compressed air without any preliminary heating and was put on to full load straight away without any trouble whatever. That was a very great advance. Since then that particular engine had been working in the factories of one of his clients side by side with one supplied by the same firm six years previously—of the type which the Author mentioned in his Paper as the 1909 type. The two were driving dynamos coupled on the same bus-bars. By regulation of the rheostats the load was divided equally between the two engines, and both had been working day by day for a period of several months, with the utmost regularity, both as regards power output and oil consumption. Oil consumption was, after all, the practical point by which the performance of engines was properly tested, and day by day the log showed that the 1915 engine used

18 gallons of oil per day, while the 1909 engine used 24 gallons of oil a day. The latest engine was therefore working with three-fourths of the consumption of oil of the earlier engine, which proved very convincingly that the improved thermal efficiency of the new type could be regularly maintained in everyday work. Some engineers received remarks about thermal efficiency with a grain of salt, knowing that while the highest thermal efficiency from one engine could be obtained under suitable conditions, in practical experience such promises and estimates were sometimes not fulfilled. The result of the working of the two engines to which he had referred, however, seemed to show that there was now no longer any necessity to doubt the possibility of the maintenance of thermal efficiencies in practical work.

The Author had referred to the past and the present, but he had not said much about the future. The speaker noted that the Author's firm had not yet put forward a two-cycle engine. The two-cycle engines had the advantages of simplicity, as had been pointed out in the Paper, but they also possessed disadvantages of low mean-pressures and lower economy, and the speaker had a decided preference for four-cycle engines, all things considered. Probably future development would be in the direction of higher speeds. The 260 h.p. engine represented very strikingly what could be done in the way of massive design, but did not the experience that most of the members had had in the war with high-speed engines tend to show that an attempt could now be made at a higher-speed engine of that type, so as to get a larger power in a smaller space? When it was borne in mind that the "Tanks" housed engines of 300, 225, and 150 h.p. in a very limited space, he thought an indication was given of what engineers must try to do in the future.

Mr. W. T. BELL, O.B.E., desired to thank the Author for the extremely lucid Paper he had presented. As one who manufactured the two-cycle engine, of which illustrations had been shown, he agreed to differ from the Author in regard to their advantages

(Mr. W. T. Bell.)
and disadvantages. The simplicity of the two-cycle engine, which dispensed with all air-valves and exhaust-valves, was a great advantage when it was in the hands of unskilled users.

Mr. S. G. MARTLEW asked whether any particular procedure was adopted in connexion with the annealing of the connecting-rod bolts; also, at what periods during the running hours did the Author consider it desirable to take the valves apart, clean them, and draw the pistons?

Mr. J. V. COONAN said that Mr. Livens' exceedingly interesting Paper had taken the members back a few years in gas-engine history. His own experience went a little further back than that referred to in the Paper, and in that connexion he thought there was one firm who were pioneers in the building of oil-engines, and who should receive more publicity than they had hitherto done, namely, Priestman Brothers, of Hull. He was glad that the President had referred to the so-called Diesel type of engine, because for a great number of years he (Mr. Coonan) had had a strong feeling against using that name, as he considered that Diesel had no right to claim what he did for his engine. When he had a particular engine pointed out to him as a Diesel engine, he replied: "Do you mean that engine which Priestmans brought out some twenty or thirty years ago?" In going round Messrs. Robey and Co.'s works during the previous afternoon he noticed a card on an engine with the words, "Semi-Diesel Engine," and inquired the meaning of the words, and what was the Diesel part of the engine, but he did not get the information. As an engineer, he felt very strongly that the engines in question should not be called Diesel engines, and he hoped the Institution would take some action with a view to preventing the name of Diesel being used, because he had no title whatever to the invention.

Mr. L. St. L. PENDRED (Member of Council) said he did not know whether it was due to the magnanimity or to the folly of the engineers of Great Britain that they had missed so many

opportunities of bringing their own people to the front, while at the same time they had taken every opportunity of advancing foreigners. At a recent Meeting of the Institution he protested against the use of the word "Kingsbury" for what was essentially the Michel thrust-bearing. One of the Papers to be read and discussed later on in the morning was on the Uniflow Steam-Engine, which was a British invention. Old Jacob Perkins was the first to introduce it, and certainly Todd had a great deal to do with it, but it was not until it came back to England from Germany as the Stumpf steam-engine that any notice was taken of it. Precisely the same thing had happened in connexion with the Diesel engine. In this country both Priestman and Akroyd Stuart were working at the same problem that Diesel was working at, only Akroyd Stuart was nearly ten years ahead of Diesel. Diesel compressed pure air in the cylinder to a high temperature, and then by means of a little higher pressure he blew oil into it. The heat of the compression was sufficient to ignite the charge. The process involved the use of a compressor which stood a very high pressure, and it was a very awkward thing to make. On the other hand, Akroyd Stuart, following precisely the same lines, compressed pure air in a cylinder, but instead of bothering with a compressor he just "chucked" the oil straight into the hot compressed air, so that to all intents and purposes he had the same cycle without all the trouble of the high-pressure compressor, which had always been the bugbear of the Diesel engine.

Although he was afraid it was impossible to follow the President's suggestion that the use of the name "Diesel" should be given up altogether, because it was still necessary to use that term to denote the engine in which air was used to force the oil into the cylinder, engineers certainly ought not to use that perfectly absurd title "semi-Diesel engine." He hoped that if possible the Institution would pass a resolution that whenever the words "semi-Diesel engine" appeared they should be replaced by the proper name, either "hot-bulb engine" or "Akroyd Stuart engine." Personally he preferred the latter, in order that British engineers might honour one of their own people.

The PRESIDENT, in closing the discussion, said he wished to make another prophecy, namely, that the Ruston engine, not being encumbered with an air-compressor, and not having to supply the power for driving that air-compressor, would in due course give a better economy than 0·4 lb. of oil per b.h.p.-hour. Theoretically it ought to give the same consumption per i.h.p. as a Diesel engine. It did not quite do so at present, simply because it was still young, and many little points in connexion with it, which he had no doubt would eventually be detected, had not yet been discovered. With the same indicated economy as that of the Diesel engine, the brake economy, which was what was required, would be better by reason of the fact that an air-compressor had not to be driven.

With regard to what had been said about the name of the Diesel engine, he proposed to suggest to the Council, with the approval of Members of the Council present at the Meeting, that a Nomenclature Committee should be established for oil engines, to deal with the question generally, and he hoped one of the results of the labours of that Committee would be to call the cycle which had just been discussed the "Akroyd cycle." The name "Diesel" was so much ingrained that probably it could not be got rid of altogether, but it might be reserved for those oil-engines which required an air-compressor.

Mr. F. H. LIVENS, in reply, said he was exceedingly obliged to the members for the kind manner in which they had received his Paper and for the interesting remarks that had been made by the President and other speakers. He had on his notes a suggestion for formulating appropriate names for oil-engine cycles, and he was heartily glad to think that the Council of the Institution would now take the matter in hand. The question asked by Mr. Martlew with regard to annealing the connecting-rod bolts was a highly technical one, on which experts differed. It was quite certain that the annealing of a bolt was not an operation to be put into the hands of any unqualified person. If such bolts were made of suitable material in the first instance, he thought that after a few years it was better to take the bolts out and replace them by spares,

the original bolts being returned to the manufacturers to be dealt with. Sometimes two years was spoken of as the limit of working, but it entirely depended upon the condition of working. In one case the engine might work night and day, and in another case only forty-seven hours a week, so that what suited one situation would not suit another.

With regard to the question of the cleaning of the piston, valves, and combustion chamber, he confirmed Mr. Tookey's statement that it was found that the higher compression engines required less attention and less cleaning. The appearance of the pistons was a guide, but it was advisable to draw them once in three or four months to remove any carbon in the grooves, which might arise from the lubricating oil. The valves should be examined and ground in if required every three or four weeks, but the combustion chamber could go on for an indefinite length of time without cleaning.

THE HUMAN FACTOR IN INDUSTRY.

By ALEXANDER RAMSAY, of Lincoln.

The prosperity of an industrial community is largely governed by the efficiency and energy of its wealth-producing classes. Of these the brain-worker is not the least important. To him we owe the comforts and refinements of modern society; he has been eager to wrest from nature the secrets she carried in her bosom and mould them to the use of man and the progress of humanity. He has devoted himself with enthusiasm and sacrifice to the patient and laboured elucidation of scientific truths which have added much to the knowledge and resources of the world. He made possible the marvellous productive capacity of a machine and labour-saving age. His place in industry, his training, scope, and encouragement would afford an interesting and profitable study. But the most perfect piece of mechanism is without value unless guided by labour. The most brilliant product of the mind cannot become material until labour has performed its function. The whole structure of industry is ultimately at the mercy of those who work with their hands. Their attitude towards the problems of

production is of supreme importance, and inasmuch as that attitude at the moment gives rise to some anxiety, it is to this phase of the subject that attention will be directed.

The country is still in the aftermath of the War. Over a considerable period it became accustomed to a prodigal expenditure of wealth without particular scrutiny of the value received. Employers and workers alike were dipping into a purse which seemed bottomless; expectations were high; rewards were high; the art of spending was tremendously encouraged. It is obvious, of course, that during this period the nation was disposing not of its revenue but its capital, and that to such a process there must be a definite and speedy end. Moreover, the continued expenditure of capital resources has the effect not only of dissipating wealth but of rendering it impossible to create more. The employers are very rapidly appreciating this truth and taking suitable action; sections of the workers appear to act as if the national wealth were illimitable and bore no relation to that which is produced.

The activities of the workers are divided in two main channels which are rapidly converging—the industrial and political. In the industrial sphere attempts are made to secure better conditions from the individual employer or group of employers, and in the political to obtain general advantage, and to effect ultimately a fundamental change in the organization of industry by the nationalization of the means of production and exchange. These ambitions are perfectly understandable and legitimate, and if the workers believe in them they are entirely justified in pursuing them; but there is an unfortunate disposition amongst a section of the leaders of the labour movement to regard the employer as one who stands between them and their reasonable aspirations, and who must accordingly be fought by every weapon at command. No apparent regard is paid to the fact that the institutions he represents are the foundations of the State, and that such merely destructive activities immediately react on the prosperity of the community. There is a tendency to seek the fulfilment of the new idea, not by the cumulative effect of sound constructive work, but by the destruction of the present system on which, until something

better is evolved, the livelihood of the whole nation depends. In other words, these doctrinaires are consciously at war with the present organization of industry, and their attitude is expressed in a general encouragement of mistrust, impatience, antagonism, and complete indifference to productive efficiency. It would not be true to say that the bulk of the workers are dominated by this idea, but the application of their unreasoned philosophy leads to very much the same thing.

The past six years have witnessed a tremendous development in the status of labour—against which there is nothing to be urged. Wages have largely increased, hours of work have been lessened, and the organization of the workers has been enormously strengthened. But with this new sense and experience of power, certain irresponsibilities have resulted which are most disastrous. In a certain industry, for example, subsidized by the taxpayers, the wages have increased 300 per cent, and individual output, it is alleged, has fallen at least 50 per cent. Most of the great trade unions of the country have declared against working a system of payment by result in spite of the most complete safeguard for the inefficient, and in spite of the fact that this system is beyond all question the most effective to induce production and in principle the most equitable to all concerned. Over a considerable period there has been a national embargo on the working of overtime. Avoidable overtime is an evil which cannot be defended. Overtime on a key operation is on occasion an essential, which it is sheer folly in these times to refuse. Overtime to pour a casting to provide work for a gang of men or to release a cargo steamer to catch a tide, are instances which would have been acknowledged, had there been any disposition to examine the question on its merits; and still demand follows demand for further and increased advantages.

These circumstances are not referred to by way of recrimination, but because they indicate an attitude of mind. They indicate that the workers do not believe that the country is now in such a position that only greatly increased production can save it from industrial disaster. They do not realize that their well-being can

only be assured, provided they are able to exchange freely the manufactured articles they produce for the commodities which they must obtain from other peoples; and that, too, in competition with other manufacturing communities similarly situated. They do not appreciate the fact that the cost and bulk of our production must determine the cost and bulk of those things we desire to import for our maintenance or comfort, and that to this extent the cost and standard of living would appear to be factors largely governed by themselves. They are holding out both hands to grasp at privilege and do not count the cost.

This in brief is the pressing problem with which industrial statesmanship is faced. Many of the industries of the country, if not already there, are rapidly drifting into a position which is economically unsound. If the tendency to take out of industry more than is put into it is further pursued, or if the destructive theory is more extensively accepted by the workers that the debilitation of the present organization is, in itself, something desirable to achieve, there is before the country a period of grave economic crisis and social danger. Industry cannot be subsidized indefinitely by the taxpayers, or carried on out of capital resources, and unless the nation settles down to work and produces what it seeks to enjoy, it cannot escape the disaster resulting from the defiance of such elementary need. It is desirable that some other means than bitter experience be found of demonstrating that it is useless to evolve theories of distribution if nothing exists to distribute, because in the times we face, disillusionment and distress are evils that will not live alone.

Now the probability is that the situation has not got beyond a point where it can be regulated, provided the mind of industry addresses itself to the problem. A remarkable combination of circumstances, due to the War, and necessitating continuous employment at whatever cost, have given the workers an unbalanced perspective and created illusions which, in the nature of things, cannot be maintained. It is unthinkable that a usually well-balanced community would commit economic suicide if it realized what was taking place. The average British workman in his

individual capacity is pre-eminently a sane and reasonable being, and he will rise to meet a necessity which he understands. The need for educative propaganda therefore is pre-eminent.

It is a first necessity that he should be made to understand that he is getting a "square deal." His spirit of reason can only be approached through his spirit of fair-play. It has been a striking fact that in the seething turmoil of the mining industry, excessive demands have not been justified popularly, on the ground that the miner's conditions of employment were improper, so much as on the ground that he desired a larger share of the profits which he alleged the employers were making. The cotton industry has recently witnessed a financial manipulation whereby stockholders have realised a capital appreciation of remarkable extent. Is it to be supposed that the spinners will be satisfied until they have shared in the spoils? The plain fact is, that the workers are now strong enough to exact a fair proportion of the profits of production, and it would be wise to make it quite clear that the employer shares in their desire. Let the employers attempt to create an atmosphere of good-will, and reciprocated good-will can at least be possible.

If two parties are inseparably associated, and differences arise which cannot be ignored, peace will be best assured by frank and friendly discussion. In this connexion the National Industrial Conference was a splendid conception, and it is a great misfortune that its potentialities have not been more fully developed. But the individual can do a great deal. Those acquainted with the problems of management should, wherever possible, establish personal contact with the worker and keep him in touch with the world factors affecting the particular product on which he is engaged. But one of the main difficulties of laying an effective case before the men lies in the fact that in a large workshop it is only possible for the directional heads to get into personal contact with a very few individuals. These delegates may be perfectly honest, but it is unreasonable to expect them when reporting discussion to accept the employer's outlook and represent it in convincing fashion. The shop steward cannot be regarded as the

best means of propagating information which the employer believes the individual worker ought to know. It is suggested, therefore, that the institution of the factory journal or house organ should be much more extensively developed, either for the individual factory or a group of factories, and that in its columns should take place from time to time a full consideration of the various domestic problems which constantly arise. A wise works director, who could have a weekly talk with the bulk of his employees through such channels, would achieve a work, the importance of which could not be measured.

Some attempt too must be made to demonstrate to the public at large the governing factors on economic questions. It has not been realized, for instance, that the tremendous increase in the price of labour and raw material is making it impossible for the country to finance the volume of output of which it is capable, with a consequent reduction in the purchasing power of the nation. It is not understood that every increase now made is simply making the evil more pronounced, and defeating the very purpose for which it was designed. Subsidized houses, transport, coal and other commodities, have been accepted with the utmost complacency, and a feeling has been created that such political strategies can be substituted for work. There has been no real insistence on the fact that the primary duty at the moment is to produce in the utmost quantity at the cheapest rate, and that instead of the studied indifference experienced, the whole of the community should be mobilized to this end.

The time has come, too, when the mischievous interference by Government Departments in industrial negotiation should be considerably curtailed. It cannot be eliminated, because the Government is responsible for the maintenance of law and order in the realm; it is the custodian of the interests of those not directly affected by a dispute, and, as such, is an interested party whose voice when necessary must be heard. But it has been proved on many occasions that a Government is too susceptible to outside considerations. Expediency is the only recognizable note of its industrial policy, and where it is quite well known that

one party to a discussion will always give way to expediency, the other may well be expected to remain obdurate. The workers are clearly entitled to receive from industry the greatest advantage which industry can afford, but this line cannot be overstepped without grave menace to themselves. There comes a time, therefore, when necessity must govern; and this point can best be determined by the directional heads of industry on the one side and the trade unions on the other.

Finally, our industrial and social difficulties can be eased by the efficiency of the employer. He it is who in a very real sense has to keep running the wheels of industry, and on him depends to no small extent the economic security of the country. But has the inanimate side of production been reduced to the science it might become, or is industry still instinct with the conservatism of old-established practice? Is the art of production studied or does it simply evolve? Much time and money could be saved if the lessons of experience were anticipated or even supplemented by the training of the schools.

It is advisable that employers should cultivate more the practice of the open door. They should develop a community of interest, interchange ideas, treat each other not as competitors but as coadjutors. No individual is strong enough to withstand the tendencies of the times, and these certainly call for unity of purpose, knowledge, and action. The hope of the future lies in the possibility that capital and labour may develop a better understanding and encourage a mutual inclination to further each other's reasonable aspirations. Such an end would have magnificent results, but it will not be attained until the nation consciously strives to bring it about.

Discussion.

The PRESIDENT said the members had listened to a very able abstract of a very remarkable Paper, the whole of which he personally had read with great care. It was a new departure on the part of the Institution to have a Paper on such a subject, but, in view of the fact that the question was of the utmost interest and importance at the present time, he hoped there would be a good discussion. He asked the members to pass a hearty vote of thanks to the Author for his Paper.

The resolution was carried by acclamation.

Mr. P. W. ROBSON, O.B.E., said he had given a very great deal of thought to the aspect of affairs which had been so ably dealt with in the Paper, and he had come to the view that there was much to be gained by realizing the phases through which they had passed, and which might in one respect be considered to have come to a conclusion in 1914. The phase from George Stephenson onwards up till 1914 might be regarded, to put it into concise terms, as a kind of experimental period, during which industry on a large scale was being applied to society. During that experimental period the forms of mechanical appliances and engineering efforts of one sort and another came not by any law; they evolved, and there was no particular sequence in them. That, of course, was a characteristic of every evolutionary period. The broad result of that was that industry had caused society to become accustomed to it and to lean upon it, without there being any guarantee that it was capable of fully supplying the needs of society. In that respect they had not reached the point when the production of wealth was commensurate with the growth of the aspirations of the people. It seemed to him that the war period had brought that experimental time—he was speaking purely from the social standpoint—to a conclusion; and, owing to the general quickening of the aspirations of the masses, which was indeed a healthy sign if

it was used rightly, they now had society demanding that the experimental period should cease and that an organized and intensive effort should be made by industry to meet its needs. Society was now going to demand from engineers that there should be an end of empiricism, and that by organized and intensive effort society should be supplied with what it needed. Putting it more or less in concrete terms, and not calling it philosophy, that, he thought, was what it came to. When the matter was realized from that standpoint, he ventured to think that, however awkward or trying might be the transitional period through which they were passing, there was no ground for permanent pessimism. It was a transitional period, and he thought it was going to lead to something better.

With regard to the attitude of labour, power without responsibility was of no use to society, and, however it had arisen there was no doubt whatever that for the moment there were evidences and frequent exhibitions of power without responsibility. It was clear that that must come to an end. He returned, a few days ago, from visiting Austria, where a new Republic had been established, and where various new laws affecting industry had been brought into existence. The net result appeared to be good; the effect was all in the direction of getting away from that anachronism of power without responsibility. There was a certain amount of power given to the workers, but it was coupled with responsibility. In connexion with each works a small number of the staff and a small number of the workpeople were appointed as representatives, and the various problems of discipline were handed over to them. He was speaking now about that kind of discipline which was so disagreeable to those who had to manage large works, namely, misconduct, unpunctuality, or other breaches of the rules. Those questions were handed over to the Committees and were being dealt with extraordinarily well. That kind of thing might appear unusual if they looked backwards, but he was not at all sure that it was unusual if they looked forwards. He had no doubt that developments of that sort would be seen in the future. What he would venture to emphasize in viewing all those matters

(Mr. P. W. Robson.)

was that there was a demand that those in responsible positions in industry should view the situation with great patience and from a very large and broad standpoint. By patient guidance he thought they would emerge from the present unhappy position and reach something better than they had ever had before. What must be avoided was any idea that it was possible to go back to the old methods of control of industry which formerly existed.

He thought the War, and the feelings and ideas which it had stimulated, had put an end to what might be termed the Victorian methods of running industry. The workers possessed different ideas, and he thought people in general ought to be glad of that fact; to some extent they were in the position of a hobbledehoy. He said it with deep respect, because he was only speaking of their mental evolution. A youth was often seen with all the physical strength and the energy of a man but without the mental experience rightly to guide that energy, and he then did some rather extraordinary things. In his opinion, that was the position with regard to labour thought. They had taken that thought collectively; it was in the position of having a great deal of power and strength which it liked to throw about, but it had not yet obtained sufficient wisdom and experience to know how to use them best. But was not that natural when the whole thing was considered as a period of growth? When one remembered what the country passed through, did not one realize that all those things were natural? Some natural things were none the less disagreeable, and he thought they all looked forward to that period passing away. As the War went on, he estimated that it would take at least four to five years before the country reached normality again. He did not mention that as making a claim to any particular wisdom, but most of his friends in industry, who were then looking forward to a great post-war boom immediately the War was over, felt that it was an extreme view. Personally, he felt it was going to take all that period, and if some of those who had given great thought to the matter estimated that to be the period, and if it looked as if that would turn out to be correct, there was cause not for alarm but for courage and patience. It

was in that spirit and temper that he ventured to think the matter should be approached. At the same time he thoroughly endorsed and supported the note of earnest warning which the Author had given. Coupled with it, however, he ventured to suggest the attitude he had put forward, courage and patience, and if those were adopted he thought the country would come through all right. If the question were looked at in that way, and if both sides would endeavour to look at the matter in that spirit, he felt sure that a happy solution would be found to all their difficulties.

Mr. WILLIAM REAVELL (Member of Council) thought it was an admirable thing that the members of the Institution, who had in the past limited their discussions to purely technical affairs, should recognize, not only as engineers but as human beings, that they must consider more and more in the future the demands of those other human beings, much greater in point of numbers, who worked with them, to have a larger life. He thought it was most fitting that, arising out of the admirable Paper which had been read, some record should go forth of the opinion of members generally of the Institution on such a subject. There was no employer of labour who had not given a great deal of anxious thought to the problem. He did not know how it struck other members present, but personally he had always resented the dividing of the great productive industry of mechanical engineering in this country into the two camps of labour and capital. That seemed to him to be entirely wrong; it gave wrong impressions to all the employees and wrong impressions to the public. Although engineers became capitalists as their business grew, they did not look upon themselves as capitalists in the same sense that bankers and stockbrokers were capitalists.

He was quite sure that those who found themselves at the head of engineering businesses were more proud of their position because they were engineers and had created something, and had done some good to the world in that way, than because they might have in the process accumulated something which the workmen regarded as "filthy lucre." It had always been a difficulty to his

(Mr. William Reavell.)
mind to know how that side of the question could be made clear to the people whom they employed—the skilled men especially. He had given a great deal of thought to that point which, however, seemed to become increasingly difficult, and he believed it was the experience of all who had given much thought to the social side of the business. He found it was more and more difficult to get into touch with labour, even the men employed in his own shops and who had grown up with him. Many of those men knew that such engineering employers were not capitalists in the sense in which the public to-day regarded the word. They recognized that these engineers had been trained with them and grown up with them, and that they wanted to train their children in order that they might keep in actual touch with the work in the workshop. Nevertheless, he found it increasingly difficult to get into really close touch with his employees and to discuss serious problems with them, such as the growth of the shop steward movement, the method of defining just what subjects such a movement should discuss with them, and what subjects it was wise they should leave alone.

He did not think that engineering employers generally from the first saw any inherent difficulty or unwisdom in the working, for example, of the Whitley Council scheme in engineering shops. The delay in establishing Whitley Councils did not arise from the engineering employers; it was caused largely from the fact that the Craft Unions themselves objected to the introduction of Whitley Councils into the engineering shops. He had followed Whitley Council matters very closely indeed, and he believed he was correct in saying that the unskilled unions, such as the Workers' Union, were more willing earlier to see the Whitley Council scheme introduced between themselves and their employers than were the Craft Unions, such as the A.S.E. He thought the delay in getting into touch with important matters between workmen and themselves was more due—with all respect to the great organization of the A.S.E.—to their attitude than to the employers' attitude. Although he was not quite certain how it should be done, he was of opinion it would be a good thing if

it went forth from the Meeting of the Institution that employers generally did recognize that their workpeople—their skilled workpeople especially, but all their workpeople—were entitled to a bigger share of the good things of this life.

He agreed with Mr. Robson that none of them must contemplate the possibility of going back to the long hours and persistent overtime which were worked before the War. There must be longer periods during the twenty-four hours in which the machinery was turning round. That was obvious, particularly now that both machinery and buildings cost so much more, but it must be done by some method of double-shift system, which took into consideration the leisure which the worker himself wanted, and was entitled to have, so as to enjoy life more, rather than by a system of overtime.

It had been his experience that the great difficulty in dealing with his own people was to get rid of that suspicion which seemed to come into their minds when the head of the firm wished to call them together to discuss social matters in relation to the business. If the engineer put his views down in the Press the workers either distrusted them or did not read them, because the same Paper was not read by the engineer and by the worker. If the head of a firm asked the men to meet him during working hours, they probably replied: "The governor has got some game on or he would not do that." If the workers were invited to meet the head in their own time they replied: "Our time is our own, and we are not coming to hear the governor talk." Colloquially he thought that put the situation as many of the members had found it to exist. If it could go forth from the Meeting that employers did not regard themselves so much as capitalists but rather as co-workers with their men in helping to get the increased production which was necessary to keep in the forefront this country of which we were so proud, and that they were as ready as the men, and more ready than the men appeared to have been in the past, to discuss works problems, he thought it would be all to the good.

The PRESIDENT said he was very sorry to have to close the

(The President.)

discussion on such an interesting Paper, but as two other Papers still remained to be read he would ask those members who desired to make any further remarks to send them in in writing for insertion in the Proceedings. He hoped the members of the Institution in general would take the matter up and thus help in solving a most difficult problem. He would ask Mr. Ramsay to reply in writing to the whole of the discussion.

Mr. F. R. WADE, M.B.E., asked if the discussion on the Paper could not be adjourned and finished in London.

The PRESIDENT said the suggestion was quite a good one, and it would be considered by the Council.

Communications.

Mr. LOUIS W. SMITH wrote that he took it for granted that such Meetings of engineers as the present one were held primarily to further the developments of engineering production in every way, and therefore he thought that Mr. Ramsay's Paper was singularly opportune. The greatest handicap to the progress of engineering at the present day was, perhaps, not the lack of good engine or ship design, efficient machine-tools or labour-saving devices, all of which had been brought into a higher plane during recent years, but the lack of real confidence between the organizers of industry and the manual workers. Engineers always felt the greatest pride and satisfaction in the achievements of members of their profession who showed more than average ability in research and design. Should we not at the present time also congratulate any member who was giving time and thought to the solution of this, the greatest problem of the moment? The apathy of some members of the Civil Service was, he feared, some handicap to

industry, as they now had much more responsibility than formerly, and nothing irritated the manual workers more than to see well-paid officials able to retain billets, when little trace of real energetic work was noticeable.

They all should set their face against the employment of any but the most efficient in the management or organization of industry, whether in private or Government employ, and he thought they should bring any influence to bear on Government departments to leave the leaders of industry to deal in an unhampered way with the men direct. All the leaders of industry naturally wished to assist increased production to the greatest extent possible, and he believed by example they could do so as much as by the intelligent use of propaganda (more of which latter was now needed). They should give the maximum of effort to their respective jobs, and show labour that they meant to fight hard for the reinstatement of the British position of pre-war days, which could only be obtained by increased production.

The individual British worker was all right at heart and would, if dealt with sincerely and sympathetically, respond quickly to the nation's greatest need and give this increased production, and he thought that the very small Bolshevik influence which now might exist amongst the men would soon become extinct. The welfare work, already now much in evidence in numerous larger works, would do a great deal to convince the workers that the organizers were endeavouring to give a happy and comfortable environment. The Works Magazine, which had been sold by the thousand amongst the employees of the various works associated with the writer's company (Clark's Crank and Forge Co., Lincoln), had been productive of extremely good results. The "recognition" of the Welfare Supervisor by the men, assisting to preserve good relations with the Management, had been found frequently useful. This was one essential link in any scheme which aimed at the happiness and contentment of the Human Factor with its inevitable good effect on industry generally. The various competitions and sports events gave the men encouragement to make themselves more efficient in that direction, and one seldom found that a good

(Mr. Louis W. Smith.)

"sport" was not a satisfactory workman. The atmosphere of any shop would certainly be helped by the rules of such a game as cricket.

Captain G. H. SAVAGE, R.A.S.C., wrote that he thought the subject of Mr. Ramsay's Paper was now of vital importance to the country, but very little concerted action was being taken. The writer had hoped that labour would gradually come to see and admit that, for prices to go down and for living to improve, there must be more production; instead of things getting better, however, they had become worse. The average man in the street could not judge; but employers of labour and men who came into touch with the working man, knew that there was a strong undercurrent of dissatisfaction. He thought that the majority of labour, by far, was not in support of Bolshevistic and extreme labour principles, but with so much extreme labour propaganda about, and with labour conditions in other countries so unsettled, this majority of labour was very unsettled, also very uncertain; they did not know what to think, nor what principles to accept as right.

Many of the working men knew that there was something wrong with the extreme labour view; but they did not know what it was. Meanwhile they were being continually bombarded with this extreme labour propaganda, and a man who was uncertain and unsettled could not be happy, and could not work. He thought the remedy was to give these men, in the *very simplest language*, an explanation of the economic laws and problems which affected them, and point out the duty of the individual to the community. This should be done by propaganda on a large scale. This view might be criticized as merely theorist, but it was not so. In the writer's opinion the tendency was to underrate the intelligence of the labour man. As Mr. Ramsay said, "the average British workman in his individual capacity is pre-eminently a sane and reasonable being, and he will rise to meet a necessity which he understands." The propaganda would be directed to the individual. The Author suggested the use of propaganda, but he did not sufficiently emphasize ts importance, he would even say, its necessity.

The influence of propaganda had without doubt been proved by the War, and by the War's subsequent history. This propaganda should explain these economic laws to labour, while putting forward as little as possible the employer's or capitalist's point of view. The scheme must be well run, with a definite plan and with a directorate of some considerable driving force. It must on no account be allowed to lapse, just possibly as it was coming to fruition, and it should be kept up for a year, or two years if necessary. The work need not go to extreme lengths; but an article every day could be put in all the cheap daily papers, with a heading that would attract the reader's eye. Such a course would be of enormous value. Practically the only suggestion at present to combat the extreme labour tendency, was that employers should meet their employees for a weekly talk, and should come into touch with them as much as possible. This, he thought, was an excellent idea, and it did good; but for the following reasons he did not consider that it could have any lasting effect:—

(1) The writer did not consider that the average member of a firm, who undertook to speak to his men, had the time to make himself thoroughly conversant with the economic problems, and their influence on the work of to-day. It was absolutely necessary that these explanations should be in the simplest language, incapable, as far as possible, of distortion.

(2) In these meetings, every works directorate would tell its men something slightly different; which points of view the men compared afterwards, possibly at some of their own trade union meetings.

(3) It was an employer's point of view that was being put forward, and the men were more or less suspicious of it.

(4) In every town there was a considerable number of works where these meetings between employers and employed were not held. At present the tendency for labour was toward extreme views, and it was known that one bad influence had an effect quite disproportionate to its size. He considered that the discontent of the men from the works, where meetings were not (perhaps could not be) held, taken in connexion with the specious arguments of

(Captain G. H. Savage, R.A.S.C.)
the extremists, could undermine to a serious extent the sound principles established in the works, where at any rate, to a certain degree, employers and employed understood each other at present.

There was, of course, nothing new in an educative propaganda suggestion; but the schemes that had been started seemed to lack a definite programme and driving force. If a propaganda scheme were initiated which was worked to present a much larger point of view than the employer's only, it would be seen by labour all over the country; it would be the same as a meeting at every works, and it would be one sound explanation of fundamental laws, which could be discussed by everybody. The suggested articles could form a basis for discussion at the various works meetings between employers and employed.

The question arose as to who could finance and work a large propaganda scheme. It lay between the Government, some society or institution, and the employers. He was afraid that it would devolve on the employers; and that, coming from such a source, it would be viewed with some suspicion. Personally though, he considered that after a time, as the articles were not to represent actually the employer's point of view, the working man would be convinced by sound and simple argument. If the Institution of Mechanical Engineers could exercise some controlling influence, and support some such scheme, there should be no lack of funds. There was at present too much destructive criticism going about; what was required was constructive criticism, and it was required quickly. The employer, by his better education, had learnt and could understand the economic laws. It was not his point of view, that he wished to teach to labour. He only knew that if labour could be taught the fundamental economic laws aright and could come to understand them, the working man would, of his own free will, help himself, help production, and help the country.

Mr. JOHN FEARN wrote that the Author of the Paper was to be congratulated, not only upon his able review of one aspect of the industrial problem, but also because of the privilege accorded him

of presenting the first Paper dealing purely with this aspect of the engineers' work since the Presidential Address of the immediate Past-President, in which the declaration was made, in courageous language, that the Institution should play a part in discussing the problems of administration and organization. A precedent was set by the Papers of Miss O. E. Monkhouse on "The Employment of Women in Munition Factories," and Mr. Ben H. Morgan on "The Efficient Utilization of Labour in Engineering Factories," given in March, 1918, but these clearly dealt with abnormal conditions. The Paper on "Jigs, Tools, and Special Machines," given by Mr. H. C. Armitage, touched one aspect of the problem. The broad and scholarly Address of Dr. Hopkinson, however, marked a distinct stage in the history of the Institution, and the promptitude with which his lead had been followed up augured well for the future.

It was certain that a very large proportion of engineers—probably the majority—were more concerned with the problems relating to production than to those of design, and it was therefore very fitting that the Institution should consider production in its various aspects. The engineer was, above all other men, practically concerned with the stresses and strains of inanimate materials, and the logical training derived from the study of the materials of construction should fit him for the stresses and the consequent strains caused in the industrial world by the methods of production and the environment which modern conditions had evolved.

In the short time at his disposal Mr. Ramsay could not be expected to cover the whole ground of the industrial problem, but it was of great importance that various aspects should be considered if a narrow view-point was to be avoided. The idea that the issue was one between employer and employed only (using these terms in the common sense) was fallacious. A third party entered into the problem, that was assuming the consumer was ignored. This third party embraced what, for want of a better term, might be designated the administration class, which included the brain workers alluded to by Mr. Ramsay. A certain number of these

(Mr. John Fearn.)

also belonged to the employee class, as pointed out in the discussion, but their capitalistic function was largely incidental and not an essential feature of their administrative duties. It would be within the knowledge of many Members that the leaders of the workers were fully alive to the importance of the administrative class, and that they were exercising great endeavours to bring them within the workers' movement.

The bad old scheme of dividing the industrial world into "capital" and "labour," which terms were usually regarded as synonymous with "employer" and "employed," would still logically include the administrative class with "labour" as "employed." This should in itself be sufficient to condemn a discussion based on the old division. Use of capital, brain work, and manual work, were all essential to production, but the knowledge and experience how to exercise each was also essential. Neither the owner of capital, nor brains, nor muscle, was of great value to the community without appropriate knowledge. Any discussion which ignored these facts must be largely nugatory, and whatever might be the views of individual business leaders, one might rest assured that the higher type of workers' leaders were well aware of the facts.

Mr. RAMSAY wrote that the Paper was intended as an indication of phases of the problems suitable for discussion, and in this respect it had been considerably successful. It was particularly satisfactory to note that there appeared to be a feeling that a society such as The Institution of Mechanical Engineers should bring such problems within its purview, because there was little doubt that, when the keen minds of the country were brought to bear upon this human problem, with goodwill, some substantial advance would be made towards a satisfactory solution. The discussion generally indicated that the representative employers, taking part, had a very real desire to help the workers to achieve their reasonable ambitions. One found, as a matter of fact, that this was generally true throughout the country, and when employers began really to think, in terms of this goodwill, a very big step

forward would be taken. For the times which the country had to face, there was need of a good deal of patience and wise tolerance. The operation of economic laws would, in the long run, act as the best curb on extravagant demands, and if the industrial ship were steered firmly—yet sympathetically—the country would get safely through into clear waters.

THE UNIFLOW STEAM-ENGINE.

By F. B. PERRY, of Lincoln, *Member*.

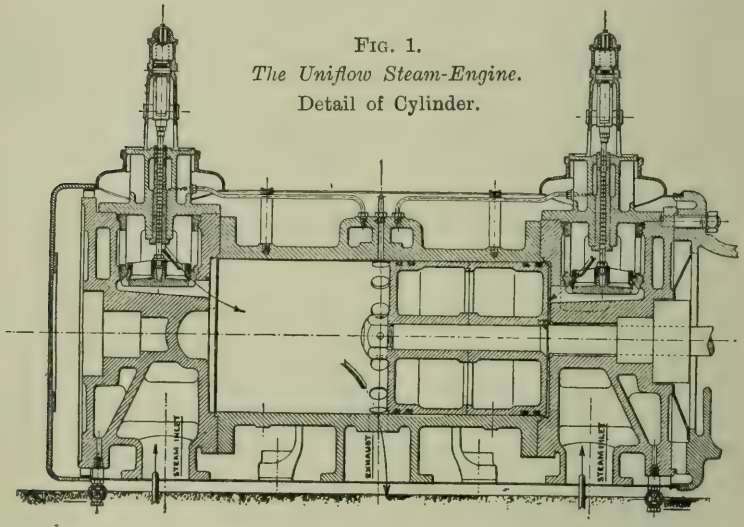
Having regard to the high price of all classes of fuel at the present time and the consequent necessity of reducing consumption to a minimum, it is thought that a short Paper on the history, principle of working, and details of construction of the Uniflow Engine, the latest development of the reciprocating steam-engine, may be of interest.

History.—The Uniflow Engine was invented in this country in 1885 by T. J. Todd. Quoting from the specification, the object of the invention was "to produce a double-acting steam-engine which shall work more efficiently, which shall produce and maintain within itself an improved graduation of temperature extending from each of its two hot inlets to its common central cold outlet, which shall cause less condensation of the entering steam, and which shall work with greater economy than has hitherto been the case."

The invention is described as follows:—"In the first place I take a double-acting steam-engine cylinder of that type which has one or more outlet openings placed at or near its longitudinal centre, and

which has also a piston so proportioned in length and which piston is also fitted in some cases with self-contained internal escape ports, and which piston is so worked, that it, by and of itself, forms the release valve, for releasing the waste steam through the central escape outlet or outlets near the end of each single stroke, and which piston also closes the central escape outlet or outlets at all other parts of each single stroke. In such double-acting steam-engine cylinders it is therefore the piston itself which forms the escape-valve and which releases the waste steam automatically near

FIG. 1.
The Uniflow Steam-Engine.
Detail of Cylinder.



the end of each single stroke, and as, in this class of double-acting steam-engine cylinders, the waste steam can only be released near the termination of each single stroke, I will herein afterwards, in order to avoid repetition, call and designate such double-acting steam-engine cylinders 'terminal exhaust cylinders.'"

The inventor's description will be easily understood by reference to Fig. 1, which shows the latest development of the invention.

Although the inventor seems to have understood the advantages of the arrangement, they were not generally recognized at the time, and the invention remained undeveloped until 1908 when

Dr. Stumpf, of Charlottenburg University, took it in hand and devised a valve-gear specially suited to the idosyncrasies of the engine. Manufacture was commenced at once by the Ersten Brunner Maschinenfabrik, of Brunn, and their example was soon followed by other continental, and by several English, firms.

Before the outbreak of the War, several hundred engines had been built and set to work for driving generators, fans, and mills; for winding, for propelling ships and locomotives, one of the last mentioned having been fitted to a goods locomotive on the North Eastern Railway in England in 1913.

The largest engine built up to 1914 was a Mill engine for a normal load of 4,000 h.p., a maximum continuous load of 6,000 h.p., and an emergency load of 8,000 h.p. This engine had a single cylinder 1,700 mm. diameter, 1,400 mm. stroke, and ran at a speed of 120 r.p.m.

Principle and Special Features.

The principle, as its name implies, is "one flow" for the steam, that is, from the hot inlet ends to the cool exhaust centre. The principal difference between the uniflow and the ordinary steam-engine cylinder is in the position of the exhaust-ports, the length of the piston, and its use as an exhaust-valve and resulting high compression.

The length of the exhaust-ports is usually 10 per cent, and the length of the piston 90 per cent, of the stroke. The clearance volume, owing to the absence of exhaust-valves and chambers to contain them, can easily be reduced to about 2 per cent of the piston's displacement. The compression ratio is therefore about 1 : 46. Under these conditions a good vacuum is necessary to prevent an excessive rise in the compression pressure. To obtain this, the condenser is usually placed immediately below the cylinder, and the exhaust-ports, practically unlimited in area by structural considerations, are made large enough to offer only a negligible resistance to the passage of the steam. Relief-valves are provided in case the compression pressure should increase excessively through leakage past the admission-valves or a fall in the vacuum. In some

cases a feed-water heater is interposed between the cylinder and the condenser.

In cases where it is necessary to change over from condensing to non-condensing, it has been usual to provide an additional clearance space in each cylinder-cover communicating with the cylinder through a valve which is closed when working condensing. This provision, however, is only suitable for temporary non-condensing working, as the enlarged clearance space and surface are inimical to economy. The best uniflow engines are now fitted with an arrangement by which they can work economically non-condensing, as the same small clearance space and surface is maintained whether working condensing or non-condensing. In locomotive engines of the uniflow type, special pistons have been used to give sufficient clearance space.

Another peculiarity of the uniflow engine is the early cut-off required to obtain a high ratio of expansion in a single cylinder. With 170 lb. pressure, 8 to 10 per cent cut-off is required for full load. For cutting off so early a trip-gear is unsuitable, and a powerful and highly sensitive governor is necessary to control the positive valve-gear needed. The early cut-off in a cylinder large enough to give the required ratio of expansion implies a high initial load upon the piston and consequently heavy working parts. The weight of these parts, however, is not without advantage, inasmuch as their inertia reduces the stresses on them and tends to equalize the turning effort throughout the revolution.

Advantages of the Uniflow Engine.

(1) *Economy.*—The results of tests for steam consumption show that, with 180 lb. boiler pressure and 200° F. superheat, consumptions of 10·5 lb. and 10 lb. per i.h.p.-hour can be obtained at full load from engines developing 500 i.h.p. and 1,500 i.h.p. respectively. These low rates of consumption are due mainly to reduction of cylinder condensation resulting from the high temperature of the cylinder-ends, the position of the exhaust-ports, the reduction of clearance surface and volume, and the high compression. The

temperature of the cylinder metal varies from point to point along the bore, from the hot end where steam is admitted to the cooler middle where the exhaust-ports are located, comparably with the temperature of the steam during admission and expansion. Indeed, the temperature gradient in the metal might be represented roughly by the admission and expansion lines on the indicator diagram.

Readings taken from a cylinder close to the inside surfaces of the cover and barrel have given the following temperatures—cover 400° F., barrel half-way between cover and exhaust-ports 250° F., at middle near exhaust-ports 160° F. So marked is this temperature

Comparative Diagrams.

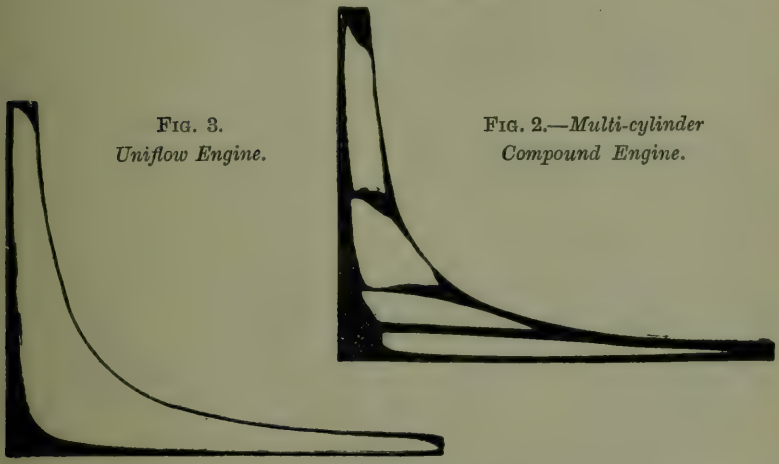


Fig. 3.
Uniflow Engine.

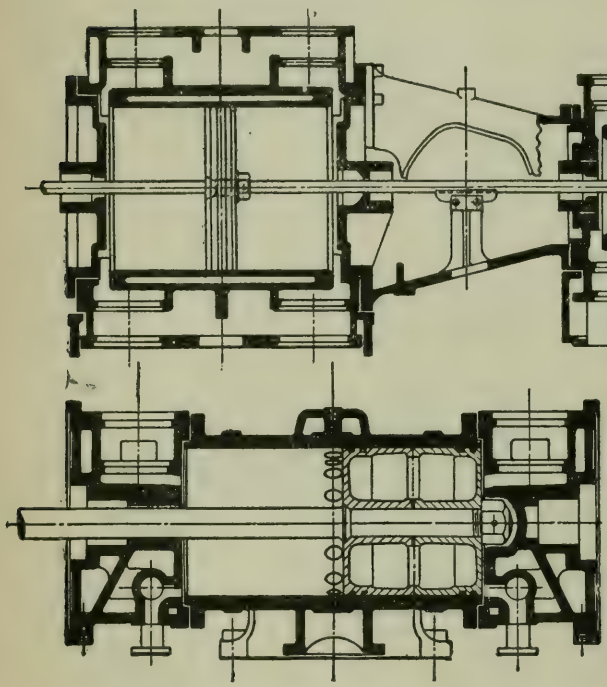
Fig. 2.—*Multi-cylinder Compound Engine.*

gradient that, to prevent trouble in working, it is necessary to bore "uniflow" cylinders barrel-shaped when cold, that is, larger in diameter at the middle than at the ends. The barrel temperatures vary very little when working either with saturated or superheated steam, due to the early cut-off, thus making this type of engine particularly suitable for superheated steam.

The high diagram factor, obtained by the suppression of the losses which occur between the cylinders and in the receivers of multi-cylinder compound engines, contributes to economy, Figs. 2 and 3, also the compressed steam at approximately admission

pressure, and the cylinder-ends which are kept hot by live steam flowing through the cylinder covers.

(2) *Flexibility.*—The steam consumption per b.h.p.-hour at full load is low, owing to the small number of glands and working parts absorbing power in overcoming friction, nor does it increase appreciably with reduction or increase of load. At three-quarter load, it is practically the same as at full load; at half-load and at

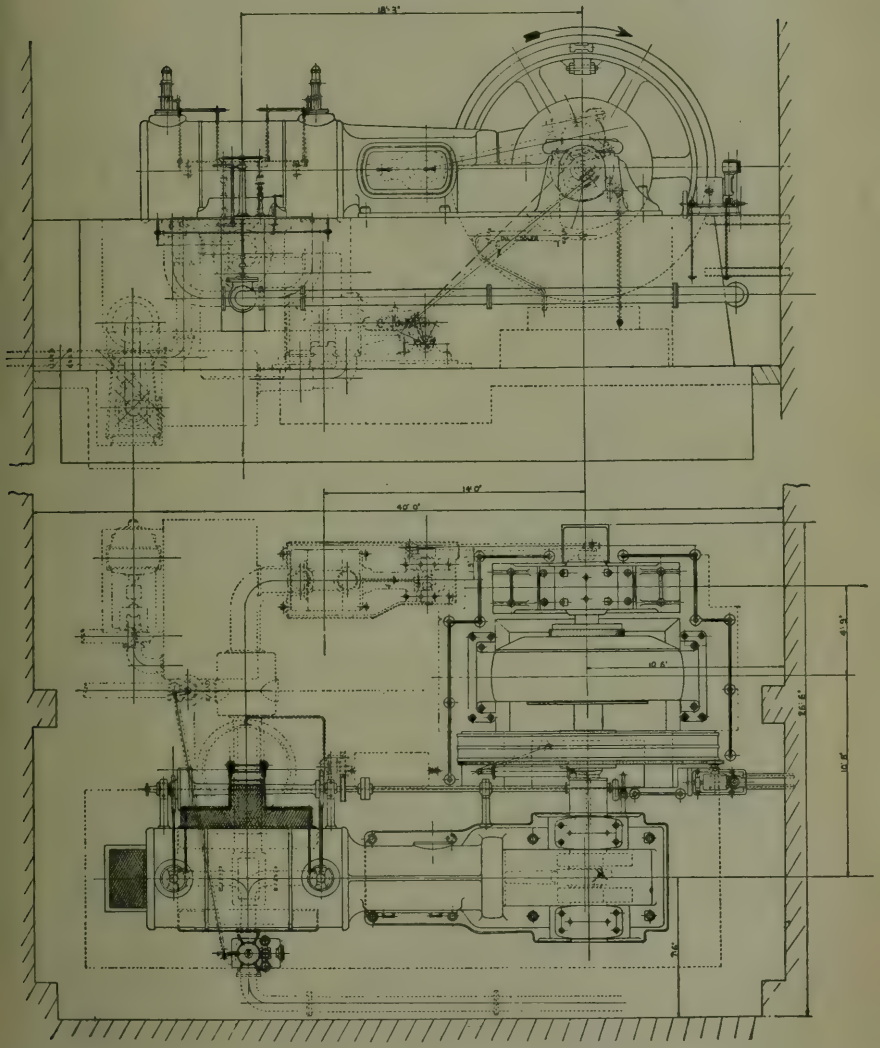


FIGS. 4 *and* 5.
Cylinders of Two Engines (Horiz. Compound and Uniflow) of equal power, same scale, showing floor space occupied.

25 per cent over-load it increases by about 5 per cent of the full-load consumption.

(3) *Speed-Control.*—It is claimed that the uniflow engine is specially adapted to give steady turning under either uniform or fluctuating loads, first because the indicator diagrams when corrected by the forces required to accelerate and retard the heavy reciprocating parts show a fairly uniform effective pressure

FIG. 7.—1,100 *I.H.P. Uniflow Engine with Generator.*



on the crank-pin, and secondly because the whole of the power is developed in one cylinder, so that any change in the position of the governor produces its full effect in a single stroke.

(4) *Upkeep.*—Compared with a multi-cylinder compound engine, which is its nearest equivalent for economy, the cost of upkeep, oil and stores will be greatly reduced owing to the extreme simplicity of this engine and the small number of working parts.

(5) *Floor Space and Foundations.*—As will be seen from Figs. 4 and 5 (page 736), which represent the cylinders of two engines of equal power drawn to the same scale, the floor space occupied by the uniflow engine is less than that required by the tandem (or any other multi-cylinder) horizontal compound engine. The foundations will also be smaller and less costly than for a compound engine.

Details of Design.

Having dealt thus briefly with the history, special features, and advantages of uniflow engines in general, the Author would add a short description of two of these engines in particular. The first, illustrated by Fig. 6, Plate 8, and Fig. 7 (page 737), was built by the Author's firm, Messrs. Robey and Co., Ltd. It is of 1,100 i.h.p. and drives a generator at a speed of 120 r.p.m., with an over-load capacity of 25 per cent for two hours and of 50 per cent for a few minutes. The steam-pressure is 200 lb. per square inch and the superheat 200° F.

The cylinder, 35 inches diameter by 40 inches stroke, consists, as shown by Fig. 1 (page 732), of a barrel, a plain casting, carrying only the exhaust belt and two small brackets for bolting to the baseplates, and of two end-covers containing the steam-valves. These last are double beat of large diameter and small lift, the upper part being movable relatively to the lower, so that the distance between the two valve-faces can always adjust itself to the distance between the faces of the seats when the latter varies under changes of temperature. The course of the steam through the covers, steam-valves, cylinder, and exhaust-valves is indicated clearly by the arrow on the figure.

In the bottom of the cover is a small passage leading to a relief and drain-valve, and in the latest engines to a small valve, which opens automatically when working non-condensing to by-pass steam to the exhaust and keep the compression at a pre-determined limit.

The piston is made in two parts as light as possible. It carries four packing-rings, two at each end, and, owing to its great length requires no tail-rod.

The admission-valves are raised by cams and rollers operated from eccentrics on a valve-shaft. This shaft also carries a powerful combined centrifugal and inertia governor which, by suitable mechanism, turns the eccentrics through small angles and thus regulates the point of cut-off.

The bed, Fig. 8, Plate 8, is of massive construction, carrying double bearings of the four-part type with circular back wedges, so that it is impossible to nip one end of the bearing on the shaft. It is attached to the cylinder-cover by eight large studs carried by bosses on the cover in order to make the surface of metallic contact as small as possible, and thus reduce transmission of heat from the cylinder to the bed. Forced lubrication is provided throughout by a rotary pump which can be operated by hand before starting the engine.

On the illustration, Fig. 6, Plate 8, a small hand-wheel is shown at the end of the valve-shaft. This permits the engine speed to be varied 5 per cent up or down while running.

The condenser is usually placed immediately under the cylinder, and the air-pump, Fig. 9 (page 740), also on the uniflow principle, is driven through a rocking-shaft from a small crank at the idle end of the crank-shaft. On the engine illustrated an oil-extractor is placed between the cylinder and condenser to prevent oil reaching the cooling tower.

The condensate enters the pump through slots in the centre of the barrel when these are uncovered by the piston at the end of its stroke, and is forced out through delivery-valves on the ends of the barrel. These are the only valves employed and can be easily and quickly changed when required.

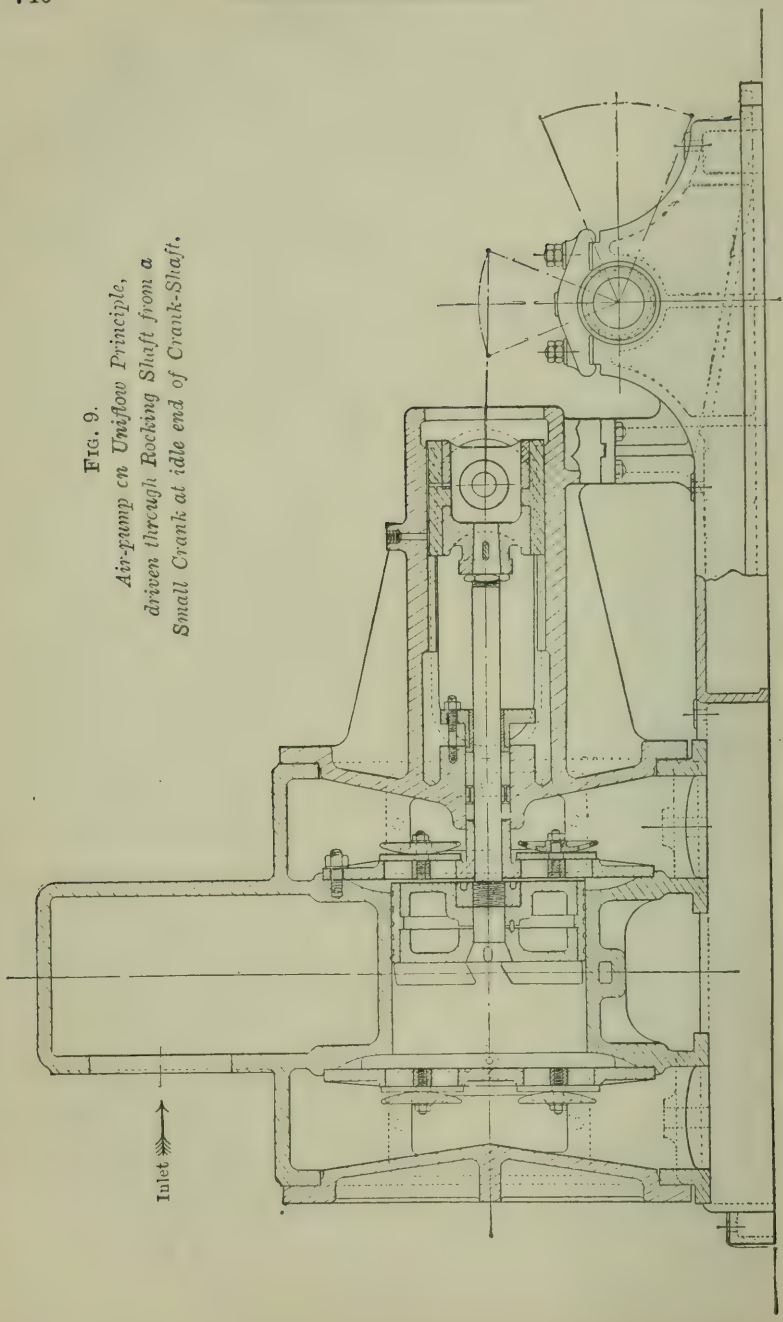


FIG. 9.
Air-pump on Uniflow Principle, driven through Rocking Shaft from a Small Crank at idle end of Crank-Shaft.

The engine last described, like most uniflow engines, runs at a fairly fast and constant speed of revolution, but there are cases in which slow and very variable speeds are needed. In such cases the engines are often of large size, and the designs for the cylinders, heavy pistons, valve-gears and governors require very careful consideration and modification.

An engine recently built by Messrs. Galloway, Ltd., of Manchester, for driving sheet mills at a steel works in South Wales is a case in point. This engine is believed to be the largest uniflow engine in the world. It is coupled directly to the mills and runs at 28 r.p.m. The steam-pressure is 160 to 180 lb. per square inch and the superheat 150° F. The general design is shown by Fig. 10 (page 742).

The cylinder, 60 inches diameter and 6 feet stroke, consists of a middle piece containing the exhaust-ports and passage, two short tubes forming the cylinder-barrel and two ends containing the steam admission-valves. The two barrel-pieces are connected to each other by bolts passing through the exhaust-belt and relieving the latter from longitudinal stress. An inspection door is provided to give access to the cylinder without removing the cylinder-end or piston.

A safety-valve, actuated by a cam-gear, is fitted to each end of the cylinder to control the compression pressure by opening automatically whenever the vacuum falls. When starting the engine, the valve is open and operates till it closes automatically when the vacuum is formed.

The piston is fitted with four rings like that already described, and is provided with a number of slippers flexibly supported and capable of independent radial movement to meet changes in the cylinder diameter due to change of temperature. The internal faces of the covers and the piston faces are polished to reduce condensation losses.

The admission-valves are of cast-iron, double beat, so constructed as to remain tight under all temperatures. Each valve is driven by an eccentric carried on a valve-shaft, the cut-off being determined by the position of a sliding block in a vibrating link, Fig 11, Plate 8.

A centrifugal governor, acting through a floating lever device,

and controlling the small balanced piston-valve of an oil-pressure servo-motor cylinder, determines the position of the block.

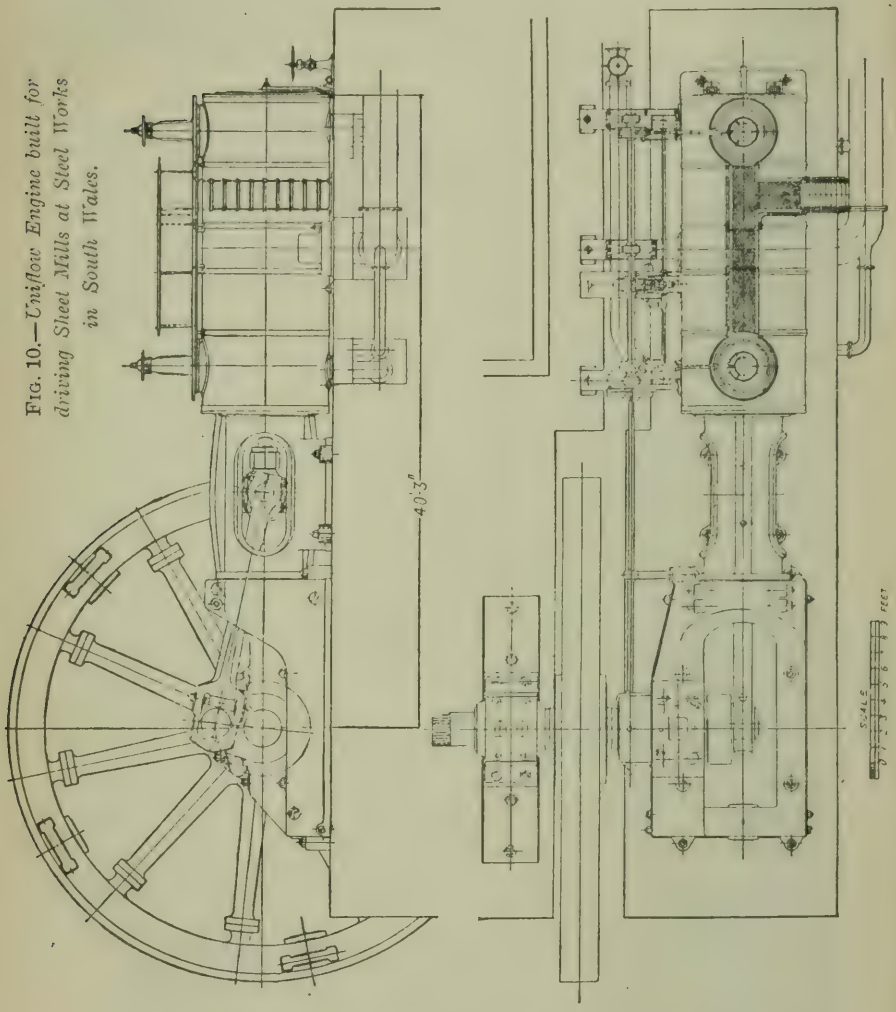


FIG. 10.—*Uniflow Engine built for driving Sheet Mills at Steel Works in South Wales.*

The piston-rod cross-head is of mild steel with shoes lined with white metal and phosphor-bronze steps, the housing for these being

cut out of the solid. The connecting-rod is forked at the cross-head end, but solid at the big end with phosphor-bronze steps adjustable by a wedge.

The crank-shaft is carried on two bearings and the crank is overhung. The fly-wheel, carried between the crank-shaft bearings, is 32 feet diameter and weighs 160 tons.

The main bearings and the crank-pin are lubricated with stiff grease instead of oil, at the request of the owners of the engine.

In conclusion, the Author ventures to express the hope that his Paper may have helped to convince the members of the simplicity, economy, and advantages of the Uniflow Engine.

The Paper is illustrated by Plate 8 and 8 Figs. in the letterpress.

Discussion.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to the Author for his most interesting Paper.

Mr. HENRY PILLING, M.B.E., in opening the discussion, said the subject of the Author's very opportune Paper had been treated with great restraint. There was enough subject matter to justify at a later date a much more lengthy Paper, in order that the extraordinary advantages which the uniflow engine possessed might be made perfectly clear. Before the War a considerable number of uniflow engines, made up to a very large size, were in active operation on the Continent, and doing extremely well. The four years of war naturally brought the position of affairs in England into a state in which it was very difficult to make progress. It might, however, be interesting to the members to know that for the first time in history the slow-speed steam-engine manufacturers of England, about thirty in number, had taken concerted action first of all with a view to carrying on propaganda work, and

(Mr. Henry Pilling.)

secondly with regard to research in thermo-dynamic matters relating particularly to the uniflow engine. He was sincerely hopeful that the necessary funds would be forthcoming for the purpose, and that the requisite energy would be displayed to bring those investigations to a successful issue.

It might be within the knowledge of the members that very little change had been made in the compound and triple expansion steam-engine during the last twenty years. In the mill districts of Lancashire the same type of engine was now being made and put in as was installed twenty years ago. In other words, the present-day manufacturer of textiles was content with the practice which satisfied his predecessors twenty years ago. In the same way, steel manufacturers were often content to put down the same types of engines for air-compressing and for rolling mills as satisfied their predecessors fifty years ago. It necessarily followed that the door had been opened very wide indeed to the enterprise of competitors who supplied different types of plant. The members of the Engine-Makers' Association, to which he had referred, were primarily mechanical engineers, and their greatest competitors were electrical engineers, who affirmed that a universal panacea for all evils was to be found in the application of electricity. It was now the intention of manufacturers of the slow-speed engine to combat that argument to the best of their ability, and they would rely in a large measure on the uniflow engine as a means to that end. He was sorry that the Paper did not include any typical indicator diagrams of uniflow engines, because they would give some point to the further remarks that he proposed to make.

The Paper had reference mainly to continuous running engines running at a constant speed, and even the large engine mentioned at the end of the Paper, which the manufacturers at present had in hand in Manchester, was also a continuous running engine of constant and not variable speed. Before the application of the uniflow engine became general, a very large amount of pioneer work had to be done by somebody. For example, before the War he was offered by a German manufacturer a very large sum of money, £40,000, if he could produce a reversing rolling mill engine

on the uniflow principle. He thought he was now in a position to claim that money if he wished to do so. During the War, types of valve-gear for uniflow engines had been developed by him which now enabled his firm to supply uniflow engines which started or came to rest automatically, which ran at any predetermined rate, then came to rest, and then restarted, and all this no matter how the vacuum might vary. The great difficulty had arisen from the fact that the uniflow engine had a high compression. In that respect it was like a Diesel engine, or rather it was like an Akroyd engine. If an oil-engine maker were asked to supply an oil-engine which would start automatically or come to rest as many times as the load on the engine might demand, he would find himself in an awkward position. If a uniflow engine were applied as a Bessemer blowing-engine, that position had to be met. A Bessemer blowing-engine working with a uniflow engine would have to run for twenty minutes and stop for ten. It would have to start either automatically or by a signal. If the uniflow principle were applied to a pumping engine, the speed would have to be fast or slow, and the engine might have to stop and start automatically.

During the War his firm supplied to the Newport Docks and Harbour Board what he thought was the largest triple-expansion pumping engine in England, and that engine was the first triple-expansion type engine which ever started and stopped freely according to the position of the accumulator. It would start or come to rest or develop any desired speed up to full speed without the slightest difficulty. If he were asked to supply that engine to-day he would offer it in the three-crank uniflow type with suitable provision for relieving automatically the compression when starting or stopping.

He thought it would be clear to the members that existing uniflow engines up to date had valve-gears which were intended to cut off not later than 30 to 40 per cent of the stroke; some modification in the gear would have to be made in order to obtain late cut-off to facilitate automatic restarting. A new and, he thought, very interesting form of gear had therefore been devised by him which worked on the hydraulic principle. Instead

(Mr. Henry Pilling.)

of the valves of the uniflow engine being opened by cams and similar details, they were pumped open. The gears that were running at present were singularly quiet and extremely attractive to the eye, and the manufacturers expected the new fashion in valve-gears to please customers to their very great mutual profit.

The question of the reversing rolling mill was closely wrapped up with the question of winding engines. His firm had received inquiries for winding engines on the uniflow principle, but there again a serious difficulty arose, and from what he had already said, the members would appreciate that if they cared to exercise their mental faculties, there was plenty of room for them to do so.

With regard to the general design of the uniflow engine, to his mind a certain lightness of touch and delicacy of design was required of a character far and away different from that required for the ordinary steam-engine. Considerable harm had been done to the movement in England by the ill success of certain manufacturers who "rushed in where angels feared to tread." It was very important, when dealing with uniflow engines, that questions relating to parallelism of cylinders, support of the pistons in the cylinders, tightness of the valves, and the arrangements for avoiding knocking at all speeds, should be thoroughly thought out. Designers should not overlook the fact that the piston load was based on full boiler pressure, with the result that the initial load was heavy. No matter how strong an engine was made, there was a linear stretch on the engine due to the application of the steam-load, and in all engines an unavoidable lengthening and shortening of the engine was observable as a necessary result of the elasticity of the material. It followed that, in the construction of the engine, efforts should be made to reduce that movement to the lowest possible point. The transmission of forces round corners and the introduction of bent frames or flanges would give rise to considerable movement, and should be avoided. Generally speaking, the class of draughtsmanship and technical skill required to make a good uniflow engine was of a very superior quality. In the old days gas-engines of common types could be made by anybody, but that did not apply to the oil-engine of the present day, and the uniflow

engine was of the latter order. Given the necessary skill in design, he looked forward to the uniflow engine occupying the highest possible position in the future.

Professor G. F. CHARNOCK said one or two details in the Paper appeared to have been passed over rather lightly, probably on account of the small amount of space into which the Author had been compelled to compress his valuable material. In the first instance, mention was made of the release-valve, which was an important and essential detail. He had seen a very neat and, he thought, efficient apparatus in use for that purpose. Fig. 12 (page 748) shows in section the cylinder-head of a uniflow engine as made by Messrs. Cole, Marchent, and Morley, Ltd., of Bradford, with the arrangement of steam-valve and gear, and their drain exhaust and relief valves, the action of the latter being shown diagrammatically in Fig. 13. The enlarged section (left of Fig. 12) shows the piston drop-valve A in bottom position. The lap for ensuring steam-tightness will be noticed, and it was claimed that this valve comes to rest without shock.

Referring to the arrangement of drain exhaust and relief valves shown in Fig. 13, P and Q are two valves working independently. The outer valve P is held to its seat by the compression of the spring R, thus acting as a relief-valve only, whereas Q is operated by the cam X, which engages with the roller V carried upon the end of the rod T, the latter being coupled to the valve-lever S. When starting up, the hand-lever W is placed in the upper position shown by the dotted centre lines, and marked "Drain." In this position, it will be seen that the roller V is forced against the cam during its whole revolution, thus keeping the valve Q, which now acts as a drain-valve, constantly open. When the engine is hot, the hand-lever is moved down to the position shown in double lines, and marked "Exhaust to Atmosphere." The roller V is now raised so that it engages only with the toe of the cam X, which is arranged to open the valve Q during the exhaust stroke. The engine, therefore, acts as an ordinary four-valve engine exhausting to atmosphere. When the vacuum has risen sufficiently, say to

(Professor G. F. Charnock.)

FIG. 12.—*Cylinder-head of Uniflow Engine.*
(Cole, Marchent, and Morley, Ltd.)

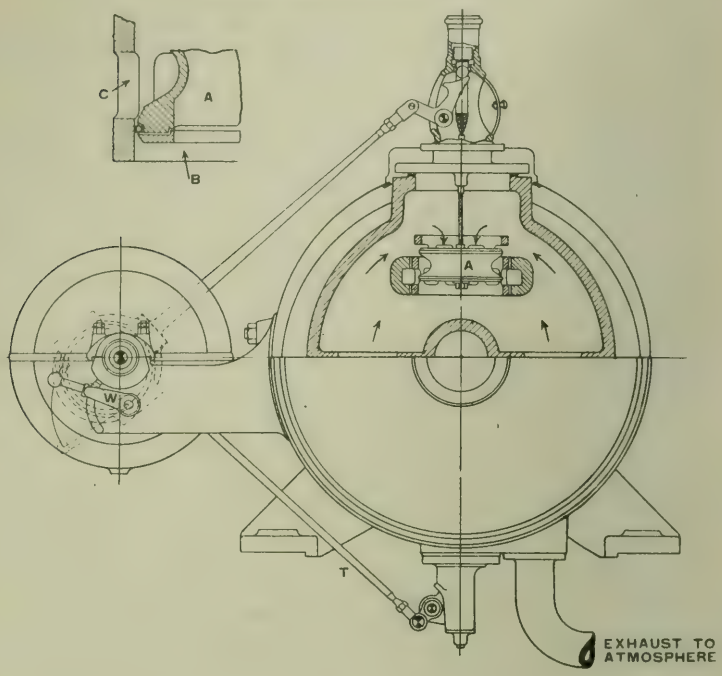
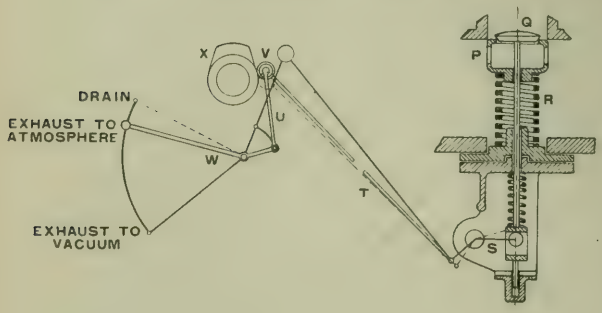
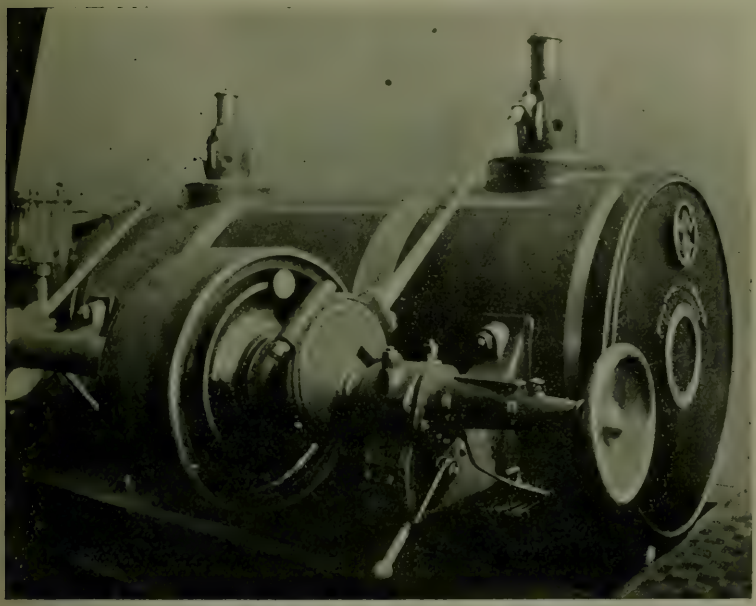


FIG. 13.—*Arrangement of Drain Exhaust and Relief-valves.*



about 20 inches, the hand-lever is dropped to the relief or running position shown in full centre lines, and marked "Exhaust to Vacuum." The roller V is now thrown quite clear of the cam, and the valve P, when required, comes into operation as a simple relief-valve working against the spring R. Fig. 14 is a shop photograph showing the arrangement of the steam eccentrics with

FIG. 14.—*Arrangement of Steam Eccentrics.*



the guard removed, and the hand-wheel for operating the governor. The hand-lever for operating the drain exhaust and relief-valves will also be noticed.

Another point he desired to raise was that of the steam-tightness of the valves. For many years past engineers had been told that the double-beat valve was absolutely steam-tight. In the uniflow engine steam-tightness was an essential feature. Even the firm which had identified itself from the very commencement with the use of the double-beat valve seemed to have found it necessary to

(Professor G. F. Charnock.)

employ a spring seat, and the Author had mentioned that the valve he was using was made in two parts for the same reason. He would like to know whether it was possible to construct a valve of that type which was perfectly steam-tight; and if the Author could give any information on that point it would prove of great use.

A third point in connexion with the uniflow engine which was worth attention was the fact that it was a single-crank engine, and it would be of interest if the Author could state or produce a diagram showing what degree of uniformity in turning was to be expected from it. Until recent years, for many driving purposes engineers had been taught that a single-crank engine was to be avoided, and that steady turning could only be obtained by a two-crank cross-compound engine. Uniformity of turning in a spinning mill was a matter of vital importance; it was perhaps quite as important as extreme economy in fuel. A single-crank engine must necessarily have two dead-points, and whatever the Author might say about the possibility of equalizing the turning moment, by taking advantage of the inertia of the heavy parts, did not get over that fundamental difficulty. It would also be of interest if the Author could show some diagrams or give some information regarding the speed variation which occurred per revolution in the uniflow engine.

At the present day, when a very large quantity of steam was required for heating purposes for process work in manufacturing, it was incumbent upon all engineers to do what they could to utilize the heat in the exhaust steam. Heat in the condenser was wasted to the extent of 60 per cent of the heat generated by the combustion of the fuel, and it seemed the height of folly not to make arrangements wherever possible for utilizing that heat. In the uniflow engine it would necessitate putting on an additional cylinder. The high-pressure cylinder would be of the ordinary type; there would be the extraction from the receiver and a low-pressure uniflow cylinder. That again would be a tandem engine subject to the disadvantages which he believed were inherent in a single-crank engine; but it appeared essential in these days

not to lose sight of the fact that something should be done to utilize as much of the waste heat as possible in that way. He would be glad to know if it had fallen within the Author's experience to design engines of that type.

Mr. P. W. ROBSON, O.B.E., thought it might be of interest if he stated that, in connexion with a large Russian factory with which his friend Mr. Blakey and he were closely associated, they purchased some two years before the war a 500 kw. uniflow engine, by Messrs. Sulzer Bros., and he would like to endorse all that had been claimed with regard to the economical working of the uniflow engine by those who were interested in it. Unfortunately it was impossible to get to that factory at present, and all the records were there, but Mr. Blakey had informed him that the economy was really remarkable. The only trouble came from vibration, which no doubt the British engineers had now overcome. The way in which the lubricating and other details were worked out was wonderful, but the vibration was a little more than was almost permissible.

Mr. Pilling had referred to the necessity for a different touch in connexion with the uniflow engine. Messrs. Sulzer did an extraordinarily large business in Russia, although their prices were very much higher than those of other makers. Because of the excellence of their work and the better guarantees as to consumption of steam and lubricating oil they gave and were able to stand by, they had attained a position to command those higher prices, and he thought that Mr. Pilling and those associated with him were on the right lines in realizing that the uniflow engine did call for a higher class of workmanship and a more refined touch than most other engines.

Mr. WILLIAM H. PATCHELL (Member of Council) said that, as many of the members knew, some years ago he was responsible for several Sulzer engines being installed in this country in the Bow works of the Charing Cross and City Electric Co. Those engines ran so well that his lead in introducing them was freely copied by

(Mr. William H. Patchell.)

others, and similar sets were put down in Belfast, Glasgow, and South Wales. Having heard that some of the engines which had been put down in South Wales were being converted from cross-compound to uniflow, he at once telephoned to Messrs. Sulzer and asked if their engineer, who was a Member of the Institution, would be able to attend the Meeting. Unfortunately he was away on holidays, but he would certainly try to get that firm to send in for publication some comparative figures of the cross-compound and the engines converted to the uniflow.

He thought that probably too much was being asked from the uniflow engine. The Author was inclined to put all his eggs in one basket and to have one cylinder and one crank. He thought Professor Charnock was correct in his statement that it was impossible to look for steady turning in that way. With regard to the question of high-class workmanship, he had been astonished over and over again at the marvellous beauty of workmanship which Messrs. Sulzer put into their engines. When he bought the engines for the Bow works, twenty years ago, they were sold in competition with English engines, and they were a credit to any country.

He was very pleased indeed that a reciprocating engine Paper had been read before the Institution. He was brought up with reciprocating engines, and he said without fear of contradiction that no man would ever love a turbine as he loved a reciprocating engine. Engineers had been driven to the use of big units of 25,000 or 30,000 h.p., but if one looked at a turbo-alternator it was difficult to know at which end the turbo was! No man would look after such an engine as he would after a reciprocating engine, and he believed that, in spite of the Coal Economy Reports and the Electricity Commissioners, the reciprocating engine still had a long life before it. In many industries there was a large demand for heat and power, which could be well supplied in conjunction with a reciprocating, and especially a uniflow engine, but which could not be met by a supply of electricity.

Mr. THOMAS CLARKSON said the uniflow engine was a very

fascinating one, and the members therefore would perhaps not be surprised to learn that twenty years ago he built such an engine for a steam-car, but unfortunately it was not a success. The difficulty then experienced was the excessive compression, and the engine had to be abandoned. It would be of much interest to him if the Author would give any information in his possession bearing upon the construction of an engine of, say, 30 to 40 h.p., a comparatively small unit, running at a fairly high speed, say 1,000 to 1,500 revolutions. He remembered the uniflow engine had been tried in America on motor-vehicles with similar results to those he obtained twenty years ago. An engineer never liked to close the door to any advance of knowledge, and it might be the case that there was a possibility, with the improvements which had been devised of recent years, of making it a success.

Mr. DANIEL ADAMSON (Member of Council) informed Mr. Clarkson, in reply to his question, that some friends had had a uniflow engine working on a steam wagon for the past twelve months with complete success, but the makers were not quite ready yet to publish the particulars.

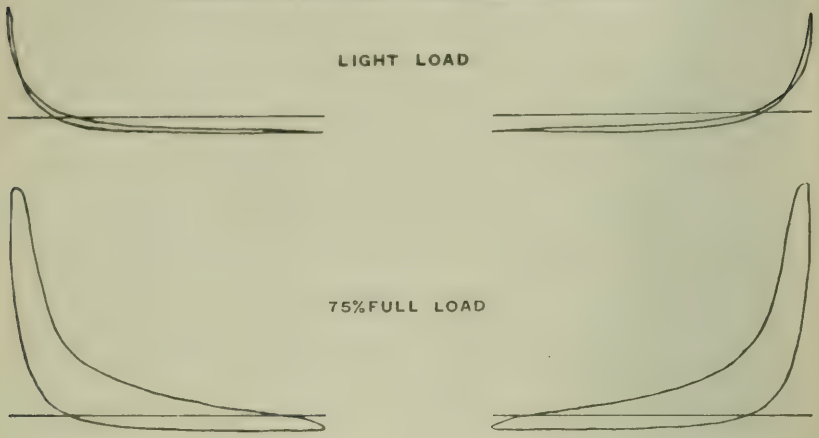
Mr. F. B. PERRY, in reply, after thanking the members for the kind reception they had accorded to his Paper, said that he much appreciated Mr. Pilling's remarks, and regretted that a more lengthy Paper was impossible owing to the number of Papers before the Meeting. In reply to Mr. Pilling's remarks on the absence of indicator diagrams, Fig. 15 was herewith inserted (page 754). The power developed when running with no load, but driving air-pump, was 5 per cent of full-load power, thus showing the high mechanical efficiency of this engine.

With regard to uniflow winding engines, some had been made on the Continent; the cost was comparable with a twin tandem engine, which was only used in large sizes, and the present practice appeared to be the use of an ordinary double-cylinder engine (which was much cheaper), combined with exhaust-steam accumulators and mixed pressure turbines.

(Mr. F. B. Perry.)

FIG. 15.—*Indicator Diagrams.*

Spring scale 128 lb. to inch. Cylinder clearance, 2½ per cent.



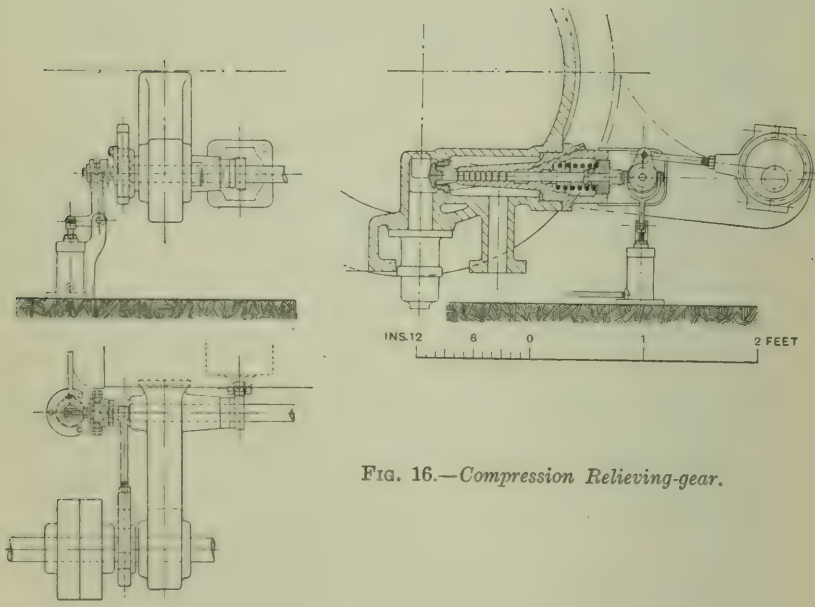
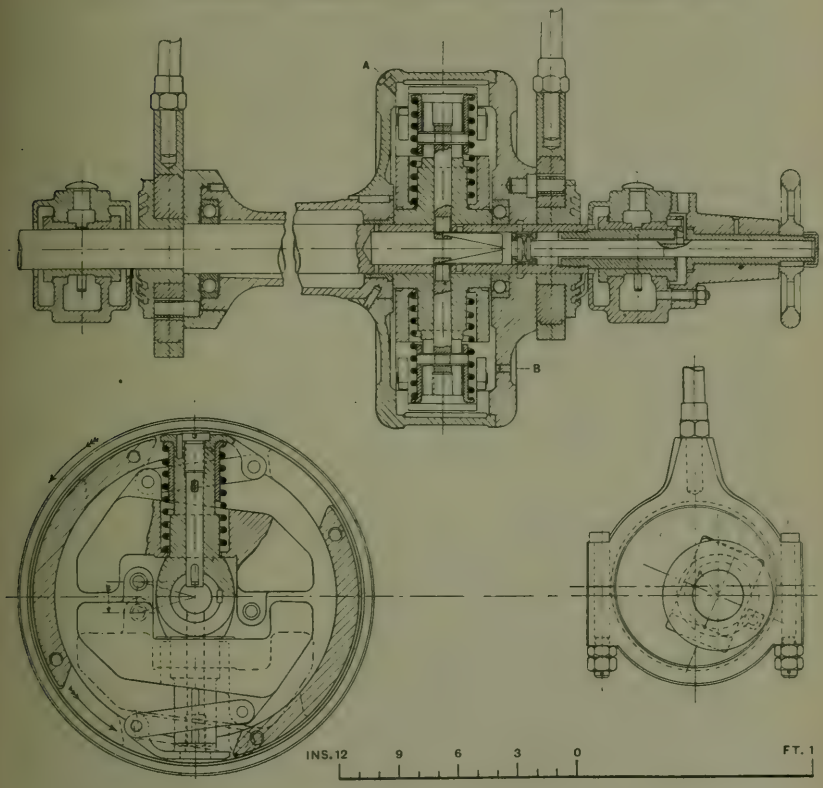


FIG. 16.—*Compression Relieving-gear.*

In reply to Professor Charnock, the Release Gear described by him had to be put into operation by hand, but Fig. 16, gave an illustration of the Relieving Gear now used by Messrs. Robey and Co. on their uniflow engines, which was automatically put into gear.

FIG. 17.—*Sectional Arrangement of Shaft Governor* (*Robey and Co.*).



This gear consisted of a small valve in each cover operated by a cam, to permit a part of the steam to pass to the exhaust to prevent the compression rising above a predetermined limit. The two cams were adjustable on a shaft, which was driven from an eccentric on the main valve-shaft. A clutch was provided at the end of the cam-shaft so that the eccentric might drive the shaft

(Mr. F. B. Perry.)

when required, or leave it stationary. The clutch was operated by a small cylinder with a piston, having one side in communication with the exhaust-belt, and provided with a spring. When there was a poor vacuum or exhaust to atmosphere, the clutch was put into gear by the spring automatically, and the cams operated the relieving valves, but when working condensing the clutch was disengaged by the vacuum, the cam-shaft was stationary, and the valves remained closed. A sectional illustration of the shaft governor used on these engines was shown in Fig. 17 (page 755).

With regard to the use of ordinary double-beat valves and steam tightness, the double-beat valve could be made and kept perfectly tight when working at one temperature, and the alteration in design which had taken place in recent years had been entirely owing to the increasing use of superheated steam. With any changes of temperature it was quite impossible always to ensure the same expansion of the valve and the seat, and, for that reason, with superheated steam a special apparatus with flexible seats had been adopted by the makers of the engines who previously used ordinary drop-valves; and that these valves were quite tight was proved by the compression line on the indicator cards, Fig. 15 (page 754).

Uniformity of turning to any degree could be obtained with a single-crank engine by sufficient fly-wheel weight, and a two-cylinder engine would only be required in an engine which had to start up from any position, as a reversing engine. Some of the earliest engines made by Messrs. Robey and Co. were for driving alternators mounted on the engine-shaft, to run in parallel where only the smallest cyclical variation was permissible. The criticism of the single crank would also apply to tandem steam-engines and gas-engines, of which large numbers had been made driving alternators. The single cylinder was cheaper to build and was more economical than a two-cylinder engine. At starting, the compression could be relieved, and there was no difficulty whatever on this point.

Where steam was required for process or heating purposes, he always put forward an engine to utilize the exhaust steam in

preference to condensing. As mentioned by Professor Charnock, where the steam could be used at a pressure above atmosphere, it was extracted between the high- and the low-pressure cylinders, but in cases where the whole of the steam provided by the engine could be used at or about atmospheric pressure, a single cylinder would be provided which would work against the back pressure of the steam being used for heating or process work.

He was much obliged to Mr. Robson for his remarks with regard to the economy of the uniflow engine. He thought the vibration of which Mr. Robson complained must have been due to insufficient balance-weights on the crank-webs. With the uniflow engine exceedingly heavy reciprocating parts were used, and it was necessary very carefully to balance them in order to reduce vibration.

In reply to Mr. Patchell's remarks, he had already dealt with the question of steady turning by the use of a heavy fly-wheel. With regard to the class of manufacture of English makers, he thought Mr. Patchell referred mostly to the engines produced a good many years ago, and at the present time he could find several makers in this country who could manufacture an engine equal to those of Messrs. Sulzer in every way.

In reply to Mr. Clarkson, he had not yet considered a small high-speed engine of the type mentioned by him, as the smallest engine he had so far made had developed 50 h.p. at about 220 revolutions.

In conclusion, he hoped that the members would have recognized from his Paper that the unique feature of the uniflow engine was the elimination of initial condensation, and that it was this feature which gave the low steam consumption at all loads. The simplicity of the engine also gave a high mechanical efficiency, and this assisted in obtaining the low consumption figures per b.h.p. at the light loads. That condensation was practically eliminated was borne out by experiments which were made on a uniflow engine at Dresden Laboratory,* which showed by means of thermo-couples and indicators recording temperature that the temperature at the

* Zeits. des Ver. deuts. Ing., 5th July, 1913.

(Mr. F. B. Perry.)

end of the compression period was considerably higher than the steam admission temperature, so that the high-pressure steam on being admitted to the cylinder entered a space which was already filled with high temperature steam.

FIG. 18.—*Steam-Consumption Curve.*

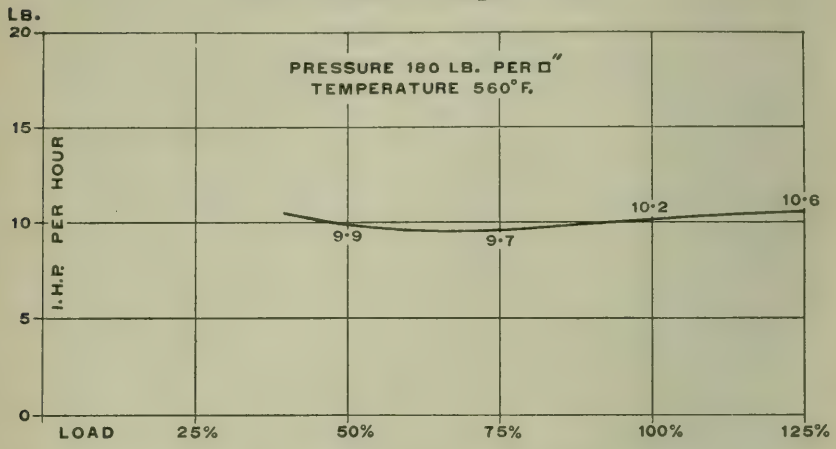


Fig. 18 illustrated a steam-consumption curve for a 700 i.h.p. uniflow engine, which showed the consumption to vary very little between 50 per cent of full load up to 25 per cent overload, and it was only with the uniflow engine that such a curve could be obtained.

Communications.

Mr. J. R. HOPPER wrote that Mr. Patchell mentioned in the discussion (page 752) that he hoped Messrs. Sulzer Brothers would furnish some particulars of uniflow engines made by them. The writer's own firm, Messrs. W. Hopper and Co., Engineers and Ironfounders, Moscow, built rope and belt fly-wheels for Messrs.

Sulzer's engines, which were imported into Russia. One of the latest pre-war jobs of this kind was executed for one of that firm's engines, which should supply valuable material for further discussion, not only of the merits of the uniflow engine, but of the other question raised in Mr. Perry's Paper, namely, the utilization of exhaust steam for process work, as the engine to which he was referring was a combination of the two systems. He (Mr. Hopper) was unfortunately prevented from bringing any engineering notes out of Russia, but was able to give sufficient particulars from memory. The engine, of 3,500 h.p., was supplied to the Russian Paper Mill Co. in Petrograd in 1914; it was horizontal side by side, a pair of single cylinders, actuating each a double-sweep crank at opposite ends of the main shaft with the fly-wheel in the middle between the engine-frames. One cylinder was uniflow-condensing and the other, of ordinary type, might be worked condensing or non-condensing, the exhaust steam in the latter case being used for manufacturing processes in the paper mill. The fly-wheel which was made by the writer's firm, was about 18 feet diameter and 12 feet 4 inches wide, grooved for 57 ropes, 2 inches diameter, in three parts in the width bolted together at the rim, each part in halves with boss and arms cast in. The weight of the fly-wheel was about 70 tons, and the ropes from it drove direct three very large wood-pulp grinding machines, requiring for their work the full power of the engine. The rest of the paper-making machinery was driven by electric motors supplied with current by a steam turbo-generator of about 1,000 kw. in the same engine-house. On inspecting the engine, he did not notice any shocks or tremors to the foundation, such as were mentioned by one of the speakers at the Meeting. This was the more remarkable as the paper mill was situated on one of the islands in the Delta of the River Neva, subject to inundations, and where piling and other expedients had to be employed to secure firm foundations.

With regard to the history of the uniflow steam engine, he thought it would be of interest if a translation were given of an abstract from Dingler's "Polytechnisches Journal," 1915, page 51, in which it was pointed out that a Belgian patent had been taken

(Mr. J. R. Hopper.)

out by Professor A. Rateau on 29th May 1894. The description of the engine, he thought, bore a striking resemblance to that given in Mr. Perry's Paper, and some of Professor Rateau's claims were given herewith. In the arrangement of the engine no exhaust-valves were required as they were replaced by the action of the steam-piston, and the compression began at once from the commencement of the return stroke of the piston. Ports were shown in the cylinder-walls in the middle of its length, opening communication with the exhaust passage, as soon as the piston at the end of its travel uncovered these openings. The piston must, therefore, be of a length almost equal to that of its stroke. If, for instance, the length of the piston were equal to $\frac{9}{10}$ of the length of its travel, the exhaust lead would be 10 per cent, and the exhaust ports would remain open during a period which was equal to $\frac{1}{5}$ of a revolution of the crank-pin. Professor Rateau also stated that, although the period of exhaust was comparatively shortened, steam was ejected with vehemence because the ports had collectively a very large area, approximately from $\frac{1}{4}$ to $\frac{1}{3}$ of the piston. He also stated that the high compression on the return stroke had an excellent effect on the efficiency as the cylinder was warmed up.

Owing to the complete compression on the return stroke, the reversal of pressure on the crank-pin and crank-shaft bearings took place long before crossing the dead centres under reduced load, so that in double-acting engines the shock from this cause was much reduced and in single-acting engines entirely eliminated.

Mr. J. E. RYCROFT wrote that, having regard to the importance attained by the uniflow engine as a development in steam-engine practice, a Paper on the subject was overdue, and Mr. Perry was to be congratulated on taking the opportunity presented by the Summer Meeting. About ten years ago the writer saw the first uniflow engine installed in Bradford. Trouble with this engine arose from the fact that the makers had not taken the obvious precaution (mentioned in the Paper) to barrel the cylinder, with the result that the piston seized, and by abrasion pieces of metal were torn out of the cylinder. Six years ago the writer was present at the

official trials of one of the first Sulzer engines installed in Bradford. This was an engine of about 500 i.h.p., which had run satisfactorily day and night since 1913–14, and on visiting the same engine a few weeks ago, it was stated that the cylinder and piston were found to be in a satisfactory condition when opened out during the early part of this year.

Many statements were made by the Author without furnishing evidence on which they were based. As an instance, the latter part of the second paragraph on page 734 should be proved by working out an actual case from an indicator diagram in order to show that the effect of the heavy working parts was to equalize the turning effort during the revolution. In this connexion it would be useful to know the coefficients of "energy fluctuation" and "speed variation" employed when estimating the fly-wheel weight, and if the speed variation was realized by the engine in actual work. In order to keep the variation in velocity during a revolution of about the same amount as for an engine with two or more cranks, it was admittedly essential to increase the weight of the fly-wheel in the single-crank uniflow engine; this not only imposed an increased load to keep the fly-wheel revolving, but increased the frictional resistance in the crank-shaft bearings

Steam consumptions per i.h.p. were given (page 734) as 10·5 lb. and 10 lb. per i.h.p.-hour for engines developing 500 and 1,500 i.h.p. respectively. The value of this statement (also paragraph 2 page 736) would be enhanced by giving full particulars of the trials when the performances were obtained. It would be of interest to know if Fig. 3 (page 735) was an actual copy of a uniflow indicator diagram, and if the expansion lines on Figs. 2 and 3 represented the measured steam fed into the cylinder. The actual diagram factors and clearances were not stated.

He would be glad if the Author would furnish copies of speed-variation records or tachograph diagrams in support of the claim made in paragraph 3 (page 736) and a detailed drawing of the double-beat valve to a larger scale than on Fig. 1, along with statements as to its steam-tightness with varying amounts of superheat. If the valves did not leak, and the steam actually present in the cylinder

(Mr. J. E. Rycroft.)

estimated from a trial, were plotted on a uniflow indicator card, this should verify the small amount of cylinder condensation claimed for the uniflow.

Particulars of trials of the two uniflow engines referred to earlier in this communication, and in the Table below, the trial of a tandem compound engine of about the same size and working under similar conditions were also given, and compared well with the results given in the Paper. The Table was taken from the Proceedings of the Bradford Engineering Society, 1916, and was supplied by Mr. Adams, who carried out the trials.

Synopsis of Test Results.

	No. 1 Uniflow.	No. 2 Uniflow.	Tandem Compound.
Indicated horse-power	588	492	513
Steam Pressure (absolute) . . .	157	155	157
Superheat (degrees F.)	218	126	158
Vacuum.	26·75	26·3	24·5
Hot-well temperature (degrees F.) . .	99	107	101
Temperature corresponding to exhaust pressure, F.	117	121	137
B.Th.U. per min. per i.h.p. . . .	220	209	243
Thermal Efficiency . . Per cent	19·2	20·2	17·4
Efficiency Ratio . . . Per cent	68·5	76·0	68·0
Lb. of steam per i.h.p. per hour . .	10·9	10·8	12·56
Percentage improvement on Compound Engine based on B.Th.U./i.h.p./min.	9·5	14·0	—

Mr. Adams stated that No. 2 Uniflow was of superior design to No. 1, built two years later by different makers. With the same superheat as No. 1 the result would have been still better.

Mr. F. B. Perry wrote, in reply to Mr. Rycroft, that the effect of the heavy parts equalizing the turning moment was dealt with in Professor Stumpf's book, and diagrams were also given. That the fly-wheel, which need not be heavier than in a tandem engine, did not cause appreciable friction loss, was shown by the no-load

Fig. 19. Fig. 20.

indicator diagram, Fig. 15 (page 754), in which the power developed was only 5 per cent of full load.

The steam consumptions given for 500 and 1,500 i.h.p. engines in the Paper were based on the test given below.

Steam-Consumption Test.

Cylinder diameter	29 inches.	Superheat	181° F.
Stroke	33 inches.	Vacuum	26·5
R.P.M.	140	Hot-well temp.	103° F.
Indicated h.p.	684	Lb. of steam per i.h.p. per hour	10·2
Steam pressure	175 lb. gauge.		
Temperature	560° F.		

Figs. 19 and 20 are illustrations of the special double-beat valve

(Mr. F. B. Perry.)

used by Messrs. Robey and Co. in their uniflow engines, and the tightness of these valves was proved by the compression curve which in all cases showed that the valves must be perfectly tight.

Fig. 19 gives a view looking on the top of the valve and shows the loose top-seat, which was held in position by steel-plate springs and kept tight by being made a ground fit, and also fitted with an internal spring ring. Fig. 20 shows a view looking on the underside of the valve.

NOTE ON NEW POWER-STATION FOR MESSRS. MARSHALL, SONS AND CO. GAINSBOROUGH.

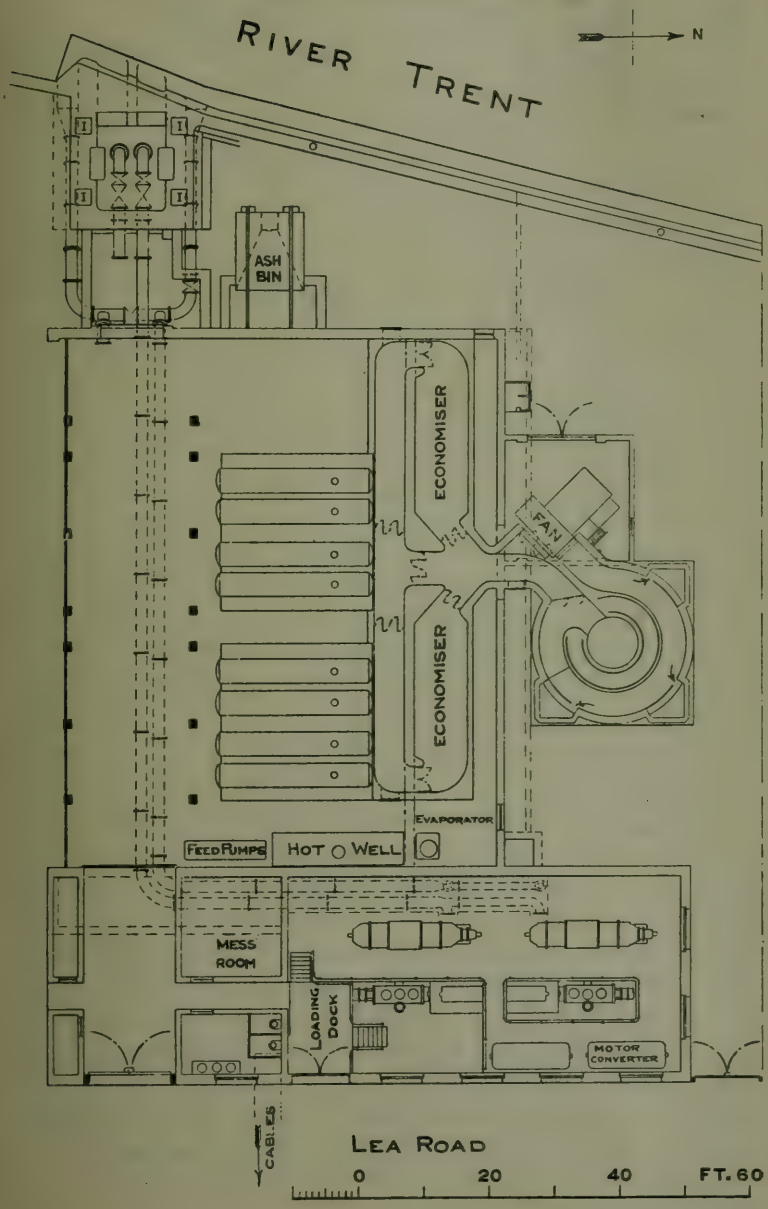
By F. J. CRIBB, of Gainsborough, *Member.*

In the year 1916 it became daily more evident that the electric power and lighting station at the Britannia Works was totally inadequate for the Firm's requirements It was running very uneconomically at double its rated load, and as all the engines were continuously running, no time was available for any repairs, and consequently all were in very bad condition. It was then decided by the directors to install a new plant. As there was no available space in the works, a new site had to be found, near the river, if possible, to reduce the yearly outlay on water which up to this time had been supplied by the Town Council and was costing over £800 per annum. For some time no likely site was available, but early in 1917 an old oil mill on the bank of the Trent, half a mile from the Britannia Works, was advertised for sale. This was purchased at Easter, 1917, and plans were put in hand for the

new plant, the conditions being that it should be able to provide a daily load of 2,000 h.p. economically and be capable of extension in the future. The Lord of the Manor also insisted that there should be no smoke or vibration, as the site was directly opposite some dwelling-houses in Lea Road and due west of a large block of workmen's houses on his estate.

Fig. 1, Plate 9, shows the site from the river, at the time of purchase. Whilst the old mill was being dismantled, plans were prepared for the new plant. Excavation was commenced in June. On putting down three bore-holes, 40 feet deep, it was found that the Firm had been fortunate in securing a site on a bed of hard red clay changing into blue stone clay in seams at about 25 feet. A curious stratum, about $\frac{1}{2}$ inch thick, of small shingle intersected the red clay all over at about 5 feet from the surface. Anyone knowing this district as being an estuary of the River Trent with its bog and sand will realize what this meant in foundations and piling, for at Messrs. Newsum's works, about 400 yards further up the river, two 24-feet piles on-end were driven down under the site for a chimney without finding any bottom, and the chimney has gone over 8 to 10 inches since being built. Even greater depth of bog was found when extending the railway bridge over the Trent half a mile further up. Whilst the excavation was in progress, a cofferdam was erected along the river frontage to allow of building a concrete river wall 26 feet high from the footing to the top, the foot being 6 feet below low water at 3 O.D., and the top of the wall 23 O.D.; the highest ascertained flood level was 21 O.D. This wall is 8 feet thick at the foot, decreasing to 4 feet 6 inches at 4 feet, and thence in steps to 2 feet at the top. Seeping holes were left in the wall at low water and half tide, and four tie-rods were secured to massive blocks of concrete 34 feet back. This wall was strengthened throughout by long lengths of angle and bar steel as the work progressed, and finished outside with pitch-pine fenders; mooring rings and posts were placed on the top. At the south end of this wall the suction-well was constructed; this was 10 feet 6 inches by 13 feet inside by 30 feet deep, having two openings to the river each 4 feet 6 inches by 12 feet high. These openings are fitted with a coarse bar

FIG. 2.—*Plan of the Buildings.*



screen and two screens $\frac{1}{4}$-inch mesh wire-cloth. Electric lifting tackle is provided for washing these screens when required.

The buildings, Fig. 2, have been arranged on the site to allow of doubling the size of the plant and to permit of a cart-road right round for convenience of coaling and disposal of ashes. For the same reason, the boiler-house was erected nearest the river with the coal-bin overhead. The generating plant is nearest the street.

The generating plant selected consists of two 1,500 kw. "Ljungstrom" turbo-generators, Fig. 3, Plate 9, running at 3,000 r.p.m. and generating alternating current at 6,600 volts, 50 periods, 3-phase, as it was found much cheaper in cables to do this, and to convert the current to 220 volts at Britannia Works by motor converters, the existing motors at the Britannia Works all being suitable for this voltage.

The switchboard is of Messrs. Reyrolles' "Iron-clad" type, Fig. 4, Plate 9, fixed on the floor above the mess-room and lavatory. There is a space between the ceiling of these rooms and the floor above to accommodate all the cable leads to the switchboard. The turbines are mounted on surface condensers fitted with tubes of "Admiralty" mixture, the water here at times being somewhat brackish.

The air-pumps alongside are of the Brush-Edwards pattern, Fig. 5, Plate 10, motor-driven, with an auxiliary pump for delivering the condensate up to a "Lea" Recorder.

The turbines are supplied with steam by four Babcock-Wilcox boilers, Figs. 6 and 7, Plate 10, each evaporating 12,000 lb. at normal load, with 3,580 square feet heating surface and 70 square feet grate area. The working pressure is 200 lb., with superheaters to give 250° F. superheat. The chain-grates and drop-links are speeded to run at from 6 feet to 24 feet per hour. The gases after leaving the boilers go through two economisers, each of 320 pipes, and from these can go direct into the chimney, or through a 55-inch motor-driven fan, which will give a draught of $2\frac{1}{2}$ inches, if required. The gases are discharged around the base of the chimney through a grit separator into the chimney The chimney is 110 feet in height by 8 feet internal diameter, and was made this height to allay the fears of the Lord of the Manor

Coal Handling.—The coal for the boilers is lifted out of the coal cellar or barge by means of a 30-cwt. electric crane with 20 feet radius, fitted with a 20-cwt. grab, and dropped into a hopper on a platform 42 feet above; this platform is carried by girders from the front of the boiler-house to four upright stanchions of 12 inches by 6 inches H steel, strongly braced, which stand on top of the suction-well and are firmly bolted thereto. The coal is filled from the hopper into a truck holding about 12 cwt., which is run on a tramway over a ferro-concrete coal-bin holding about 600 tons; a "Grizly" is fitted between the rails, and the tramway falls about 12 inches in its length, so that the load is easily pulled by a small motor fitted under the platform. After being filled, the truck is pulled over an automatic weighing-machine which registers the weight of each truck and the total weight; it then passes on over the bin and tips automatically where required, afterwards being pulled back to be re-filled from the hopper. The hopper is arranged on wheels so that if better and larger fuel is at any time obtained, a breaker can be installed on the staging. This arrangement was adopted in preference to a conveyer arrangement, as it did not take up any floor space and was considerably cheaper. Each charge of coal to the boiler hoppers is weighed automatically by a simple valve arranged on the shoots. A conveyer could not be arranged to lift from a barge, as the difference between low water and extra flood-tide might easily be 18 feet. The crane and grab with tramway truck cost slightly over £1,000, but one estimate for a conveyer alone cost £2,000, and the crane and grab were still required.

The coal-bin is provided with five electric thermometers which will ring an alarm bell in the manager's office, should the temperature of the coal rise 2° F., but as the coal is constantly drawn from the lower part of the bin, no inconvenience from spontaneous combustion is anticipated. The coal now used is of very inferior quality and of a calorific value of 10,200 B.Th.U., containing 26·28 per cent of absolute ash, 25·01 per cent volatile matter, 45·26 per cent fixed carbon, 4·45 per cent moisture; and the theoretical evaporative power from and at 212° is 10·52 lb.

Ashes.—The ashes are dumped by the dumping grate into a brick-lined ash-pan, the bottom of which is fitted with a sliding door actuated by a pinion and rack. This, when open, permits the ashes to fall into a truck in the ash-tunnel beneath; and after slaking, the truck is hauled on to a hoist which lifts the truck up and dumps its contents into an ash-bin holding 40 tons. The bottom of this bin is fitted with two valves to permit the ashes being dumped either into a barge or cart as may be desired; at present there is locally a good demand for ashes.

Circulating Water.—The water for the circulating pumps is taken from the suction-well by a 20-inch c.i. pipe built into the back wall and fitted with a reflex valve: it goes down to within 2 feet of the bottom, the bottom length of pipe being considerably bell-mouthed to reduce the speed of entry, and at the lowest tide there is 5 feet head; provision is made for a second pipe for extension. This pipe is laid in a tunnel 11 feet 6 inches wide by 7 feet high under the firing floor of the boiler house. The floor of the tunnel rises 12 inches, and the pipe has only one bend in the whole length; every joint is easily visible and accessible. The return-flow main is laid alongside; the outflow from this goes into the river, north or south of the intake, according to the flow of the tide. The blow-off main and cold-water service main are also fixed in this tunnel, together with two "Wilcox" automatic water-elevators, which lift any drain-water into the suction-well.

Cold-Water Service.—The cold-water service is pumped up by two 5-inch centrifugal motor-driven pumps into a cast-iron tank holding 6,500 gallons, fixed at the street end of the coal-bin. This tank is fitted with a rough sand-filter and a floating suction. It supplies water to the evaporator, for washing out service-pipes, circulating pump bearings, fan bearing, and lavatories.

Boiler-Feed Make-up Water.—The feed-water for the boilers consists of the condensate from the turbines and make-up feed from a 'Caird and Rayner" 20-ton evaporator, Fig. 8, Plate 11, supplied

with water from the overhead tank. The condensate from the turbines is delivered up to a "Lea" recorder and from there flows by gravity into a hot-well tank holding 6,500 gallons. This hot-well also receives the trap drains from the steam-main, the drains from the stop-valves, the exhaust steam from the turbo-feed pumps and evaporator, and its temperature is not less than 160° F. Should the evaporator fail from any cause, there is an automatic ball-valve inside the tank which will come into action as soon as the water is lowered to a fixed point. The evaporator is guaranteed to evaporate $1\frac{1}{4}$ lb. of water per lb. of steam; it may not be so economical as a softening plant, but is more cleanly in its working, and does not fill the pipes up with flocculent lime mud; it needs but little attention, once a month for about two hours, to clean the outside of the coils. By this means, the boilers are grease-clean and the labour of scaling is avoided; a little lime has to be introduced by giving a percentage of river water occasionally which forms a slight coating and prevents pitting. The river water averages from 14 to 16 degrees of hardness. From the hot-well, the water is fed to the boilers by a "Weir" single-turbo centrifugal pump, running 2,000 r.p.m., and a 6-series motor-driven "Pulsometer" centrifugal pump, Fig. 9, Plate 11. The feed-pipes are so arranged that the water can be fed either direct to the boilers or through the economisers.

Fig. 10, Plate 11, shows the elevation from the opposite side of the river, the fan-house under the chimney next to the economiser house, and boiler-house with the ashes-hoist and hopper, the firing bay with the platform and electric crane and grab. The right-hand side of the firing bay is finished temporarily with asbestos sheets, provision being already made for the roof principals of the extension. All through this plant, attention has been given to accessibility, both for repairs and information, gauges, thermometers and recorders being provided as follows:—Draught gauge at chimney; recording thermometer at chimney; thermometers at inlet and outlet of each economiser, giving temperature of inlet and outlet gases and water; CO_2 recorder and temperature of furnace recorder ("Uehling") with indicator at boiler fronts;

pressure recorder on steam-main; superheat thermometer on steam main; gauges showing head on suction and delivery of each air-pump; ammeters; vacuum gauges on delivery pipes from condensers; mercury vacuum gauge, temperature of inlet and outlet water, temperature of steam entering condenser, to each turbine; "Lea" recorder integrator; indicating and integrating wattmeters.

Old Electric Station.—This contains four engines (three to work, one as standby). In 1913, 8,997 tons of coal were burnt, costing £8,100. In 1913 water at 6*d.* per 1,000 gallons was used, costing £815. In that year 3,000,000 kw.-hours were generated, during 300 days, averaging twelve hours, and in addition two engines were running off the same boilers. These engines were giving off a total of 380 h.p., and were using about 24 lb. of steam per h.p.-hour, and boilers evaporating $7\frac{1}{2}$ lb. water per h.p.-hour (= 1,980 tons of coal per annum), leaving 7,017 tons used to generate 3,000,000 kw.-hours = $5\frac{1}{4}$ lb. per kw.-hour.

Wages for this station cost £75 per week.

New Station.—During the six winter months from 1 November 1919 to 30 April 1920, there have been generated 1,222,628 kw.-hours, and 1,556 tons 18 cwt. 3 qrs. of coal have been burnt, which is equivalent to 2·85 lb. per kw.-hour. The staff consists of four men and two women, and their wages amount to £25 per week.

The coal used at the new station is of much inferior quality to that used at the old station, although, at present, it costs more per ton and contains more ash. Further, at the old station, the pumping of the condensing water up the cooling towers and driving the fans took 170 kw. and cost, at $\frac{3}{4}$*d.* per unit, £1,912, and £815 for water.

All the auxiliaries, namely, fan, stokers, air-pumps, lifting crane and haulage motors at the new power station take only 140 amperes at 220 volts, and at $\frac{1}{2}$*d.* per unit cost £225 per annum The water supply is taken free from the Trent. At a test taken

on 18th March last by Captain H. Riall Sankey, C.B., the steam consumption of the turbines working at full load of 1,500 kw. came out at 12·42 lb. per kw.-hour, with 208 steam-pressure (gauge) at stop-valve, 192° F. superheat, and 0·80 lb. per square inch abs. back-pressure.

In daily running the above-named instruments show the following average readings:—

Steam-pressure Recorder		195 lb. to 200 lb. per sq. inch.
Mercury vacuum-gauge on Turbine		94·6 per cent abs. vacuum.
Feed-Water	Hot-well	160° F.
	Into Economiser	160° F.
	Out of „	270° F.
Gases from Boilers	Into Economiser	480° F.
	Out of „	375° to 380° F.
	Into Chimney	300° F.
Circulation Pumps	110 amps., 220 volts.	
	Head against 4–6 feet	according to tide.
	Suction against 10–14 feet	
Air-Pumps		15 amps., 220 volts.
CO_2		6 per cent, occasionally 8 per cent.

Draught-gauge on fan, 1½ inches; when using an extra fine sample of coal, occasionally 2 inches.

Speed of grate has to be varied very frequently to suit the fuel coming down from the bin.

The present load is from 1,200 to 1,420 kw.; voltage and revolutions steady at 6,600 and 3,000.

No figures are available for half-load.

The Paper is illustrated by Plates 9 to 11 and 1 Fig. in the letterpress.

Discussion.

The PRESIDENT, in moving a hearty vote of thanks to the Author for his interesting Paper, said that he made a test about a month ago of one of the Ljungstrom turbo-generators described, and the result was given at the end of the Paper. He desired to point out that the test was made with the turbo-generator just as it was working in the station on the works load, without any tuning up. When the consumption obtained on test of 12·42 lb. per kw.-hour was corrected to the steam conditions for which the turbine was designed, it was found to be just a shade under 12 lb. per kw.-hour, and the over-all efficiency ratio was 72·8 per cent, which he thought the members would agree was a very remarkable figure. About 13 years ago he tested the first 1,000 kw. Ljungstrom turbine in Sweden, the turbine being tuned up to the very last point, and in that case the over-all efficiency ratio was 74 per cent. He hoped many of the members would visit the station at Gainsborough on the following Friday, because it was of quite remarkable design. It bristled with thermometers and measuring apparatus of every kind and description, and it might be possible to carry out a short test while the members were there. He asked the members to accord a very hearty vote of thanks to Mr. Cribb for his very interesting Paper, and at the same time he expressed his regret that, owing to the time allotted for the Meeting having expired, it would be impossible to ask for any verbal discussion. He hoped, however, that those members who desired to make any remarks would send in written contributions for insertion in the Proceedings.

The resolution of thanks was carried by acclamation.

Communication.

Mr. CHARLES R. HONIBALL wrote that he had read Mr. Cribb's Paper with considerable interest, and was pleased to note his

adoption of "marine practice" to obtain pure water for steam-boiler feed make-up purposes. He had been well advised in doing this, and the writer could endorse all his statements as to the simplicity and ease of working, reliability, and effectiveness of this system. In the plant at Gainsborough, he (Mr. Honiball) inferred that the evaporator was operated in "single effect," and had sufficient heating surface to evaporate twenty tons of river water per twenty-four hours. The thermal efficiency was stated to be one and a quarter pound of water evaporated per one pound of boiler steam. This appeared to be high for a "single effect" apparatus, though easy of attainment with "double effect" apparatus. It would be of particular interest if the Author would furnish further data and particulars and explain how this high efficiency was achieved and calculated, stating pressure, temperature, and total heat in one pound of the boiler steam supplied into the evaporator heating coils; temperature of condensate; working pressure of the evaporator; and temperature of feed-water. He would also like to know where the evaporator steam was condensed, before or after discharge into the hot-well, and was its heat usefully employed?

Mr. F. J. CRIBB wrote that, in reply to Mr. Honiball's remark that the thermal efficiency appeared to be high for a "single effect" apparatus, the figures should be $1\frac{1}{4}$ lb. of steam for 1 lb. of water evaporated. This amount of steam represented the weight of water drawn from the heat coils at a temperature of about 250° F., and as this steam was returned to the hot-well and condensed, the only actual loss was that due to radiation from the hot-well which was covered with non-conductive composition.

EXCURSIONS.*

On Tuesday Afternoon, 20th July, after luncheon in the Gymnasium of the Municipal Technical School, by permission of the City of Lincoln Education Authority, various alternative Visits were made.

One was to the Stamp End and Titanic Works of Messrs. Clayton and Shuttleworth, in motor chars-à-bancs provided by the Reception Committee. The Members then proceeded by the Firm's private railway to the Clayton Forge and Abbey Works, where tea was served in the Canteen.

Another Visit was made by motor chars-à-bancs, provided by the Reception Committee, to the Globe Works of Messrs. Robey and Co., under the guidance of Mr. W. T. Bell, O.B.E., Managing Director. The Works of Messrs. Clarke's Crank and Forge Co. were next visited under the guidance of Mr. Louis W. Smith, Managing Director, after which tea was provided by Messrs. Robey and Co. in their Canteen.

In the evening the Institution Dinner was held in the County Assembly Rooms, Lincoln, the Guests and Members being received by the President and his Daughters, Mrs. Mair and Miss Sankey. The President occupied the Chair, and 200 Members, Ladies, and Visitors were present. Among the latter were Members of the Reception Committee, as follows :—

Lincoln Reception Committee : Lieut.-Col. J. S. Ruston, *Chairman ;* Mr. Alfred E. Collis, *Honorary Secretary ;* The Right Worshipful the Mayor, Alderman H. A. Cottingham ; The Sheriff, Mr. A. B. Porter, and Mrs. Porter ; The Town Clerk, Mr. W. Bagshaw,

* The notices here given of the various Works, etc., visited in connexion with the Meeting, were supplied for the information of the Members by the respective Authorities or Proprietors.

O.B.E., and Mrs. Bagshaw; Mr. William Barnes; Mr. W. T. Bell, O.B.E., and Mrs. Bell; Mr. and Mrs. F. J. Cribb; Mr. and Mrs. Edward Josselyn, *Hon. Sec. Newark Reception Committee;* Mr. and Mrs. F. H. Livens; Mr. Herbert J. Marshall; Mr. F. B. Perry; Mr. P. W. Robson, O.B.E., and Mrs. Robson; Mr. and Mrs. George R. Sharpley; Lieut.-Col. E. Mansel Sympson, M.A., M.D., and Mrs. Sympson; Sir William A. and Lady Tritton; and Mr. R. E. Westwood.

The President was supported by the following Members of the Council: *Past-President,* Dr. William H. Maw and Mrs. Maw; *Members of Council,* Mr. Daniel Adamson and Mrs Adamson; Mr. Richard W. Allen, C.B.E.; Dr. H. S. Hele-Shaw, F.R.S.; Mr. William H. Patchell; Mr. Loughnan St. L. Pendred; and Mr. William Reavell.

After the Loyal Toasts had been honoured, Mr. WILLIAM H. PATCHELL (Member of Council) proposed that of "The City and Trade of Lincoln," to which The Right Worshipful the MAYOR responded, mentioning that the rateable value of the City of Lincoln was £286,545, of which the Engineering Works represented about 14 per cent.

Dr. H. S. HELE-SHAW, F.R.S. (Member of Council) proposed the toast of "The Reception Committee," to which Lieut.-Col. J. S. RUSTON (Chairman of the Reception Committee) responded, referring to the widespread and mistaken idea that agricultural machinery was the only engineering product of the City. He stated that for many years that had not been the case, not even when the Institution met there thirty-five years ago. On the outbreak of the War great developments took place, and Lincoln produced all kinds of munitions, Tanks, submarine engines, motor-tractors, bombs, aeroplanes, mines, etc.

The toast of "The Ladies" was interpolated by the PRESIDENT, who drew attention to the fact that ladies were now eligible for election to the Institution, provided their qualifications met the

requirements of the By-laws. Sir WILLIAM A. TRITTON replied on their behalf in a witty speech.

The health of Mr. and Mrs. EDGAR WORTHINGTON was also toasted on the proposition of the President, and Mr. WORTHINGTON responded.

The concluding toast of "The Institution of Mechanical Engineers" was proposed by Mr. P. W. ROBSON, O.B.E., who dealt with the great problems awaiting solution, and urged the necessity for the establishment of a National Intelligence Department in Mechanical Engineering. The PRESIDENT, in responding, endorsed all that had been suggested by the Proposer of the Toast, and stated that most careful consideration would be given to the points that had been raised.

On WEDNESDAY, 21st July, after luncheon in the Gymnasium of the Municipal Technical School, by permission of the City of Lincoln Education Authority, Visits were made to the Works of Messrs. Ruston and Hornsby and Messrs. William Foster and Co. Proceeding by motor chars-à-bancs or by special trams provided by the City of Lincoln Corporation, the Members visited Messrs. Ruston and Hornsby's Motor Works and the Wellington Foundry (original "Tank" Works) of Messrs. William Foster and Co. Subsequently, a Visit was made to the Boiler Works and Spike Island Works of Messrs. Ruston and Hornsby, by whom Tea was provided. A Garden Party was also given at Dunelm House by Mr. P. W. Robson, O.B.E., and Mrs. Robson.

In the evening a Reception was held in the County Assembly Rooms by the Lincoln Engineering Firms.

On THURSDAY, 22nd July, two whole-day Excursions were made.

One was to Scunthorpe by motor chars-à-bancs to the Frodingham Ironstone Mines, where the excavators described in Messrs. Livens

and Barnes' Paper (page 609) were seen at work on the Crosby Face, the party being conducted by Mr. R. E. Westwood, Manager. After luncheon in the Blue Bell Hotel, the ironstone mines and the Normanby Park Steel Works of Messrs. John Lysaght, Ltd., were visited, and the Members were entertained to Tea by the Firm.

The second Excursion was made by ordinary train to Newark, where the Members and Ladies were met by the Local Reception Committee. The Members proceeded in special motor-cars, provided by the Newark Engineering Firms, to visit the Woodworking Machine Works of Messrs. A. Ransome and Co., the Underfeed Stoker Works, and the ball and roller bearing works of Messrs. Ransome and Marles Bearing Co. The Ladies visited the Castle, under the guidance of Mr. W. Bradley, and the Parish Church, under the guidance of the Rev. Dr. J. M. Walker, Vicar of Newark. A Reception was subsequently held in the Town Hall by the Right Worshipful The Mayor and Mayoress, Councillor and Mrs. H. E. Branston, which was followed by luncheon in the Town Hall, by invitation of the Newark Engineering Firms.

In the afternoon the Members visited by motor-cars the Works of Messrs. Worthington-Simpson, and of Messrs. Ransome and Marles Bearing Co., and the Ladies went to the Governor's House, Beaumont Cross, the Museum, etc. Subsequently the whole party were entertained to Tea by the Newark Engineering Firms in "The Friary" Garden, by permission of Mrs. George Branston. The return journey to Lincoln was made by ordinary train.

The following Works were also open to the Visit of Members :—

Abbott and Co., Newark Boiler Works.
Farrar Boiler Works.
Ruston and Hornsby, "Bradley's Foundry."

On FRIDAY, 23 July, two whole-day Excursions were made.

One was to Gainsborough, where the Members were taken in motor-cars provided by Messrs. Marshall, Sons and Co., to visit the Trent Works (saw mills) of that Firm. They next proceeded to the adjoining Albion Works of Messrs. Rose Brothers, where the

various wrapping machines were shown, after which the Old Hall was visited by permission of Sir Hickman B. Bacon, Bart. The Members were then entertained at luncheon in the Canteen of the Britannia Iron Works, by invitation of Messrs. Marshall, Sons and Co., and were subsequently shown over the Britannia Iron Works. A letter was read from Mr. James Marshall expressing regret at his unavoidable absence. After Tea in the Canteen the return journey was made to Lincoln.

During the day some of the Members visited the new Power Station of Messrs. Marshall, Sons and Co., which is described in Mr. F. J. Cribb's Paper (page 765), also the saw-mills of Messrs. H. Newsum, Sons and Co.

The second Excursion, in which Ladies took part, was made by motor chars-à-bancs through the Dukeries, via Apleyhead Wood, Clumber Park, and Thoresby Park to Edwinstowe, where luncheon was provided at the Dukeries Hotel. In the afternoon the Major Oak in Sherwood Forest was seen, and the journey continued to Southwell, where the Cathedral was visited, under the guidance of the Venerable Archdeacon W. J. Conybeare, M.A. After Tea at the Saracen's Head Hotel, Southwell, the return journey to Lincoln was resumed.

The following additional Works were open to the Members during the Meeting:—

Lincoln Corporation Electricity Works, St. Swithin's Power Station.
Lincoln Corporation Gas Works, Bracebridge.
Lincoln Corporation Sewage Pumping Plant and Refuse Destructor.
Lincoln Corporation Westgate Water Tower and Tank.
J. Cooke and Sons, Lindum Plough Works, Monks Road.
Richard Duckering, Waterside Works.
Penney and Porter, Broadgate.
W. Rainforth and Sons, Britannia Iron Works, Monks Road.
Ruston and Hornsby, Sheaf Iron Works and Wood Works.

Messrs. Alfred Herbert also invited the Members to visit their Works in Coventry on their way to or from the Meeting.

The LINCOLN LADIES' RECEPTION COMMITTEE arranged a Programme for the entertainment of the Ladies during the Meeting.

On TUESDAY morning, 20th July, after attending the Lecture on "Roman Lincoln" at the Municipal Technical School, Lieut.-Col. E. Mansel Sympson and the Ladies' Committee conducted a party to visit The Strait, the Jews' Houses, the Castle, Newport Arch, Remains of Roman Wall and Ditch at Eastgate House, by permission of Mr. A. Shuttleworth, and the Old Palace Grounds, by permission of the Bishop of Lincoln, Dr. W. Shuckburgh Swayne.

In the afternoon, after luncheon in the Municipal Technical School, the Choral Service was attended in the Cathedral, and in the evening they were present at the Institution Dinner in the County Assembly Rooms.

On WEDNESDAY MORNING, 21st July, the Cathedral was visited by invitation of the Dean and under the guidance of the Sub-Dean, the Rev. Canon E. T. Leeke, M.A. After luncheon in the Municipal Technical School, a Garden Party was given at Dunelm House, by invitation of Mr. P. W. Robson, M.B.E., and Mrs. Robson.

In the evening the Ladies were present at the Reception in the County Assembly Rooms, by Invitation of the Lincoln Engineering Firms.

On THURSDAY, 22nd July, a whole-day Excursion was made to Newark (page 780).

On FRIDAY, 23rd July, a whole-day Excursion was made by motor chars-à-bancs through the Dukeries (page 781).

CORPORATION ELECTRIC POWER STATION AND TRAMWAYS DEPÔT, ST. SWITHIN'S, LINCOLN.

The Corporation obtained a Provisional Order to enable them to supply electricity in the city in 1897, and, after taking expert advice in 1898, inaugurated a direct-current three-wire supply from works erected on the north side of Brayford Pool, a large sheet of water in the centre of the city; which connects by way of the Foss Dyke with the Trent on the west side with the Witham on the south side, thus assuring to the works a constant supply of water for boiler-feed and condensing purposes.

At the present time these works contain about 2,000 kw. of plant. In the boiler-house there are two ranges of boilers, the one consisting of a set of five economic type boilers working at 125 lb. to the square inch saturated steam, and the other of one Climax, one Babcock and Wilcox, and two Howden boilers, all working at 200 lb. to the square inch with superheated steam. The capacities of the Howden boilers are 15,000 and 20,000 lb. per hour respectively, and of the Babcock and Climax about 6,000 lb. each. The bulk of the steam supply of the station is given by the high-pressure boilers, the old boilers being used as a stand-by for the winter peak-load.

In the engine house, as in the boiler house, the original plant was laid out for working with the low-pressure boilers, and consists of three 100 h.p. and three 300 h.p. Willans engines, coupled to Laurence Scott machines. When the high-pressure boilers were installed, triple-expansion Howden engines were put in with the first two boilers, and with the larger boilers a 750 kw. Willans-Westinghouse turbine complete, with a rotary converter enabling the Corporation to give a direct-current supply, the reason for the installation

of the A.C. generator being that the original engine-house was too narrow to allow for the extra length required for a D.C. turbine.

During the War it was necessary to give a 3,300-volt power supply to one of the large firms in the city, and this was taken from the A.C. turbo-generator by way of a step-up transformer. As the extra demands of the War expanded, the Corporation were not able to cope with the power requirements for this particular firm, the result being that the firm themselves acquired a large second-hand plant and built their own power station having a capacity of 4,400 kw. on the other side of the river from their works. This consisted of three 750 kw. turbo-generators by the A.E.G. Company, and one new 2,000 kw. by the B.T.H. Company, all operated at 3,300 volts, 50 periods. The boiler house contained four land-type Babcock and Wilcox boilers, coal being obtained off a private siding from the adjacent railway, and water from the river.

At the beginning of 1918 the Corporation, having in the interim lost other power supplies through insufficiency of plant, called in Sir John Snell on the question of expanding their generating station, and, acting under his advice, negotiations were entered into with Messrs. Clayton and Shuttleworth, the owners of the new station above referred to, and were concluded during the summer of 1918. In August of last year the Corporation finally took over the working of the new station, on which they immediately commenced extensions, which include the putting down at the earliest possible moment two 5,000 kw. turbo-alternators, generating at 6,600 volts, 50 periods, together with four marine type Babcock boilers, each capable of an evaporation of 36,000 lb. of water per hour, and all necessary auxiliaries. The contract for this new plant was placed in June of 1919, and delivery and erection was promised in twelve months. Owing, however, to the disastrous effect of the moulders' strike, the plant will not now be forthcoming until the end of the year, and probably not in operation before February or March of 1921. As the Corporation are faced with a serious shortage of plant for the winter of 1920–21, they have now decided on the immediate installation of a second-hand plant of 2,000 kw. capacity, which they hope to have in operation in October.

For the purpose of carrying out the extensions, the Corporation acquired an extra five acres of land, in order to provide for large coal storage and for buildings for a final plant capacity of about 40,000–50,000 kw. They also have to provide for the fact that during any dry spell in the summer months the flow of water in the River Witham is very slight, and therefore a large cooling tower capacity will ultimately be necessary. The ground acquired is largely in the nature of a swamp in the wet season, and the whole of the buildings and plant therefore have to be carried on piles, some 400 of which (in reinforced concrete) have had to be driven for the extensions at present in hand. The Corporation, before commencing the extensions, entered into contracts with various firms in this city, and it is anticipated that the bulk of the capacity of the two new sets will be forthwith required to supply the demand.

Since Sir John Snell became first Chief Electricity Commissioner, Mr. A. H. Preece has acted as Consultant to this Corporation in connexion with these extensions.

TRAMWAYS.

In 1901 the Corporation obtained powers under a private Bill to provide tramways for the whole of the city. At that time the only tramways existing consisted of a line of horse-drawn vehicles running from the centre of the city southwards into the adjoining District Council of Bracebridge, a distance of $1\frac{3}{4}$ miles of route, operated by a private company, working under an Act which gave the Corporation powers to purchase at the end of twenty-one years. This period expired in 1905, and the undertaking of the Company was duly acquired, and it was forthwith decided that the line should be electrified.

As Lincoln, however, was an ancient city with many architectural beauties, the Corporation of that period were of opinion that the installation of the overhead system would be an eye-sore, and it was finally decided to lay down the "G.B." surface contact system on the High Street route for trial purposes, and if it proved satisfactory to consider its installation on the other routes as in the schedule in the Bill. This system belongs to the same

class as the Loraine, which is still operated in Wolverhampton, and the Dolter, of which there is now no example in this country. It has certain advantages over these as far as the visible part of it is concerned, in that the studs are not required to project above the roadway for their proper operation, as is the case in the other two systems, as the cars on the Lincoln system are fitted with a flexible collector chain in lieu of the ridged skate required for the other two systems for the collection of electricity from the studs.

In due course the system was installed, and as it successfully stood the tests specified during the ensuing twelve months, it was eventually officially taken over. For various reasons, however, mainly because of the short lengths of the other proposed routes and the low estimated receipts therefrom, no other portions of the city have in the interim been supplied with a system of public traction, though at the present time a number of motor-omnibuses are on order for this purpose.

In the years that elapsed between the installation of the " G.B." system and the commencement of the War, its working gave considerable satisfaction to the citizens, and the costs of running were well below the average costs of the various overhead systems running in the country. During the War, however, it was very difficult to maintain a special system such as the " G.B.," and further than that the track was very much damaged by the traffic over it of such heavy weights as Tanks, the first of which came from the Lincoln works, and tractors, so much so that after the War it was found that in order to put the track into thorough working order again, it would be necessary to relay it entirely at a cost far in excess of that required to erect the overhead system, and for that reason the Corporation decided on the latter course. The order was placed during the summer of 1919, and the first car was in operation in a little over three months from the commencement of the work of conversion.

The Corporation own eleven tramcars and two trailer cars, the latter of which are used at the works' meal and other busy hours.

The depôt is at the south end of the line at present in the area

of the Bracebridge Urban District Council, but as the Ministry of Health are recommending Parliament to accede to the application of this Council that Bracebridge with other surrounding areas should be included in the City of Lincoln, this state of affairs should not be lasting.

CORPORATION REFUSE DESTRUCTOR, LINCOLN.

The refuse destructor plant for the city was erected in 1915 by Messrs. Heenan and Froude, of Manchester, to destroy the whole of the refuse collected daily, the steam generated to be used for operating the sewage pumps. The plant, separately housed, consists of four mechanically-clinkered cells charged from storage receivers above, a Babcock and Wilcox water-tube boiler, with 3,040 sq. ft. heating surface, and 160 lb. working pressure, air heater, chimney with dust catcher, water-softening plant, Robey electric generating set, electric transporter operated on the push-button principle, and steam-pipe main to pumping station.

The collecting carts tip their contents into two storage hoppers, each having a capacity of 2,500 cubic feet, and arranged one at each end of the building to facilitate tipping. Between these hoppers is a skip-pit containing four wrought-iron skips. These are charged with refuse through a movable funnel and, when filled, are raised by the push-button transporter and placed in whichever of the four storage receivers requires to be charged, the lowering out of the lifting rope effecting the discharge.

To charge the furnace-grates, the sliding door under each storage receiver is mechanically drawn forward by wire ropes working over friction drums secured to a motor-driven shaft, which operation at the same time raises the firebrick door, sealing the charging opening. This door carries a funnel to ensure that the whole charge shall enter the furnace. The grates are channel-shaped with a sliding drawbar on a raised centre. When the refuse, usually after three charges, has burned to a clinker, the drawbar is attached to a winch,

the mass of clinker being withdrawn on to a tipping clinker truck on rails, to be deposited where required. It will be seen that the arduous work usual with destructors is reduced to a minimum.

The City Engineer and Surveyor is Mr. R. A. MacBrair.

CORPORATION SEWAGE WORKS, LINCOLN.

The sewage system generally was carried out to the designs of the late Mr. James Mansergh, and the pumps were fixed in 1880. The pumping plant consists of three Lancashire steam-boilers, working at a pressure of 80 lb. per square inch. These supply steam to a pair of compound condensing engines with high-pressure cylinders, 15 inches diameter, and low-pressure cylinders, 30 inches diameter, and fitted with Davey's automatic differential gear. These actuate four ram-pumps, 22 inches diameter and 5 feet stroke, one placed below each steam-cylinder, and at ordinary working speed making fourteen strokes per minute. The capacity of the pumps is 160 gallons, but after allowing for slip, it may be taken that 145 gallons are pumped per stroke. The bottom of the suction-well is 23 feet below the floor of the engine-house, and the total height to which the sewage is lifted is 60 feet. The daily quantity of sewage pumped in dry weather is 2,200,000 gallons, but after heavy rain, the volume rises to 6,000,000 gallons per day.

CORPORATION WATERWORKS, WESTGATE WATER TOWER AND TANK, LINCOLN.

Owing to the peculiar geographical position of Lincoln, in that part of the city is on a hill and the remainder on the slope or in the valley, the difference in levels being from about 15 ft. to 225ft. above Ordnance Datum, it becomes imperative, for the purpose of

supplying water to the Uphill district, to have an elevated tank, and to support such a tank is the function of the Westgate Water Tower. Westgate—named after the old " west gate " through the wall or fortifications of the ancient Roman City—is on the hill to the north of the city in the vicinity of the Lincoln Minster and the Castle.

The tower was built in 1910–11, and is of brickwork, circular in plan, with an outside fascia of brick, square on plan with Ancaster stone facing. The design is very heavy and substantial, the quoins and bottom portion being tooled stonework, having the panels filled in with rock-faced rubble. The tower is 56 feet square outside and 48 feet 9 inches inside diameter at ground level, and is 117 feet 6 inches high to the top of the parapet wall. The circular brickwork supporting the tank is 4 feet 3 inches thick, the walls being parallel. The tower is roofed.

The tank is 52 feet diameter, of mild steel plates throughout, and has a spherical bottom. The top water level is 330 feet above Ordnance Datum. The vertical sides are 17 feet 6 inches deep and terminate in a compression member 2 feet 8 inches deep, from which is hung the spherical bottom, having a radius of 34 feet. The depth of the tank in the centre is 31 feet, and the holding capacity 300,000 gallons. The two top rings of plates are each $\frac{5}{16}$ inch thick, the two lower are $\frac{3}{8}$ inch thick, whilst the bottom is built up of $\frac{1}{2}$-inch plates throughout. The weight of the tank and contents is taken by the compression member which is a built-up girder, 2 feet 8 inches deep by $13\frac{3}{8}$ inches wide, resting on cheese-shaped rollers which again rest on a C.I. bed-plate 18 inches wide, resting on stone templates on the top of the brickwork.

Five pipes pass through the bottom of the tank, namely, three 20-inch diameter, one 12-inch and one 6-inch, a stuffing-box and gland being provided in each to allow for any upward or downward movement of the tank. Underneath the bottom of the tank a movable gantry is supplied, one end resting on a circular rail on the brickwork and the other on a centre platform or crow's-nest, supported by the three upstand pipes. This gantry will revolve from the centre platform, so that any portion of the tank bottom can be

inspected or painted. A circular staircase is provided in one of the arrises for access to the tank and roof, and a winch is provided at the tank level for the hoisting of material.

The inlet pipe (20 inches) passes up to the top of the tank and down again to the bottom to ensure complete circulation of the water and also to maintain a uniform head on the pumps. A 12-inch outlet pipe, fitted with reflux valve, comes out of the bottom of the tank into this main to supply the Uphill district when pumping ceases.

The whole of the water pumped passes into this tank, the surplus over the Uphill consumption passing from top water level down a 20-inch outlet pipe into a trunk main through the city, into a storage service reservoir built on the hill to the south of the city, which serves to feed the remaining portion of the city when pumping is suspended. This method ensures that the tank is always full when pumping ceases.

A 20-inch overflow pipe, discharging into an open-air bath near by, is provided, the bellmouth being 6 inches above that of the outlet pipe, and 12 inches below the rim of the tank. This ensures that the tank shall not overflow in the event of sudden closing of valves on the outlet main.

In the base of the tower is a vault containing all the necessary control and reflux valves, Venturi meter tube, etc. The tower was built by Messrs. G. Henson and Sons, of Wellingborough, to the design of Sir Reginald Blomfield, R.A., the tank was made and erected by Messrs. Newton, Chambers and Co., Ltd., of Sheffield, whilst the engineer for the scheme was the then waterworks engineer, Mr. Neil McK. Barron. Mr. C. Horobin is the present Waterworks Engineer.

MESSRS. JOHN COOKE AND SONS, LINDUM WORKS, LINCOLN.

These works were founded by the late Mr. John Cooke in the year 1852. He was the son of a farmer and was apprenticed at an early age to a village wheelwright. At the termination of his indentures

he started in business as a cart and wagon builder, fashioning much of the work with his own hands, and originating a number of new vehicles for farm purposes. He settled in Lincoln subsequently in order to meet an existing demand for the new types of ploughs and agricultural vehicles he had designed. One of his models was a feature of the Royal Agricultural Show in Lincoln, in 1854.

He died in 1887, leaving the business in the hands of his two sons and partners, Mr. William Cooke and Mr. Frank Cooke, of whom the latter survives. The special work carried on is the manufacture of single, double, three- and four-furrow tractor-ploughs, ridging, earthing and potato-lifting ploughs, harrows, horse-hoes, cultivators, flat rollers, clod-crushers, etc. In the vehicle department, carts, wagons, drays, traps, milk and cattle floats, liquid manure and water-carts are built.

MESSRS. CLARKE'S CRANK AND FORGE CO., LINCOLN.

This firm was founded on its present site in Lincoln in 1859. For over sixty years the Company has specialized in the manufacture of crank-shafts, and all types of general engine forgings. To-day they undertake any class of engine and marine forgings, in addition to their speciality, namely, crank-shafts. The Company has recently become associated with the Agricultural and General Engineers, Ltd., an association of many of the leading East Anglian engineering firms. In 1909 the Company was reconstructed by the present managing director, Mr. Louis W. Smith, and during the last ten years it has quadrupled in size and output. The works are now efficiently equipped with modern steam forging-presses, hammers, and machine-tools, and can supply forgings or finished machined crank-shafts up to 10 tons in weight each.

The chief feature of the forge is the large Davy Steam Hydraulic Intensifier type of press, having a power of 1,200 tons, and served by two electric travelling cranes of 30 and 10 tons capacity.

Electrical turning gears are added for the economical handling of ingots up to 15 tons each. In addition to the press, steam- and electrically-driven pneumatic hammers range from 5 cwt. up to 3 tons, all served by furnaces, the waste heat from which is used to raise steam for driving the hammers. The advantages of the forging-press are now generally recognized, and it is believed to be the most efficient and economical tool for general forging purposes, the material forged under it giving better tests than under the hammer, particularly on large work. High-speed working can be obtained, and as many as eighty finishing strokes per minute are possible on a press of this particular size.

The machine shops for the machining of crank-shafts are well laid out, and at the present time further extensions are in progress. All the machinery is electrically driven, and each bay is served by an electrical travelling crane. Heavy crank-shaft turning lathes and grinding machines are installed, a number of these having separate motors. One of the largest lathes is capable of swinging 60 inches diameter, over the saddle, and 32 feet between the centres.

Another department is also laid out for the machining of the smaller types of crank-shafts, including motor-lorry shafts, and here are seen many modern machines, specially designed for this class of work.

The annealing processes are provided for in special furnaces fitted with pyrometers. An oil tempering bath is also installed for the special treatment of forgings which are required of high tensile alloy steel, such as aeroplane and motor-car crank-shafts. Included in the machines used for testing is a 30-ton Buckton tensile testing machine, also a Brinell hardness testing machine, and further laboratory accommodation is now being provided. The firm have at present about 200 employees, and are at the moment building a Welfare Institute where the employees will have their own facilities for social events.

MESSRS. CLAYTON AND SHUTTLEWORTH, LINCOLN.

These works, established in 1842 by Nathaniel Clayton and Joseph Shuttleworth on a plot of land measuring 1½ acres and giving employment to 100 men, now cover about 100 acres and employ approximately 5,000 workpeople. The original business was iron-founding in which line Nathaniel Clayton was an acknowledged expert, being ably assisted by his partner, a skilled engineer and inventor. About this time considerable developments were being made in the steam-engine, particularly in its application to road-haulage and agricultural work.

In the year 1845 Messrs. Clayton and Shuttleworth made their first portable engine, which, with the thrashing machine, might be said to have revolutionized agriculture. The inventive ability of the founders may be judged by the number of inventions brought out during the succeeding years, including the placing of a steam-jacketed cylinder in the upper part of the smoke-box in portable and traction engines; the adoption of spur-gearing for transmitting the power from the crank-shaft to the axle; the older method of chain-drive did not die easily, as it was not until about 1870 that this was finally discarded by other makers. To date, over 120,000 thrashers and engines have been made and dispatched to every country in the world.

The products of the company now include in addition to thrashing machinery, portable engines and traction engines, steam-tractors, road-rollers, chain-track tractors, crude-oil engines and boilers, including the "Spearing" water-tube.

Recently a subsidiary company called Clayton Wagons, Ltd., was formed to take over the Titanic Works, the Abbey Works, and the Clayton Forge, to specialize on steam and electric road-wagons, railway rolling-stock and drop stampings and steel forgings respectively. This company is very closely associated with the parent company.

STAMP END WORKS.

These works cover the site of the original shop and extend to about 25 acres. The principal manufactures include steam-tractors, traction-engines, portable engines, road-rollers, trailer-wagons, thrashing machines, clover-hullers, chaff-cutters, elevators, crude oil engines, and chain-track tractors, locomotive and water-tube boilers.

Machine Shop.— Used as general machine shop for machining parts of traction-engine, tractors, road-rollers, steam-wagons, etc.

Erecting Shop.—Steam-wagon erecting shop.

Test Shed.— Steam-wagons, tractors, traction-engines, road-rollers, and portable engines, etc., undergo a thorough steam-test in this shed.

Tractor Erecting Shop.—Here, in addition to steam-tractors, traction-engines and road-rollers, will be seen the "Clayton" 35 b.h.p. Chain-Track Tractor, of which 1,000 have been built since 1917, being largely used by the Food Production Department of the Ministry of Food for agricultural purposes in Britain. They were also used for hauling heavy guns, etc., in France. It is interesting to note that the pressure on the ground underneath the track is only about 3 lb. per square inch.

Steel Foundry.—The steel foundry covers an area of 3,400 square yards and is served by one 25-ton, one 5-ton, and five 3-ton overhead electric cranes. Machine moulding machines are largely used, and include :—One Macdonald's No 12, capable of taking work about 4 feet square, and fitted with electric jarring and pneumatic lifting gear ; two No. 6 machines by the same makers, and two Britannia machines.

The steel is melted in two "Heroult" electric furnaces, each with capacity of 30 cwt. and capable of a melt every four hours. The furnaces are supplied with three-phase current at 50 cycles and 110 volts. There are two large Direct Gas Firing Co.'s annealing furnaces, and two drying furnaces.

The fettling shop is equipped with pneumatic chippers, Noble and Lund bandsaws, stationary and pendulum grinders, electric and oxy-acetylene welding plants, and a complete shot blasting plant by Tilghman, of sufficient capacity for the needs of both steel and iron foundries. A well-equipped laboratory is run in conjunction with the foundries and the drop-forging plant.

Iron Foundry.—This is in two bays, and has a floor area of approximately 2,000 square yards. The main bay is served by two electric overhead cranes in addition to wall cranes, narrow-gauge railways, etc.

The second bay, where the smaller work is carried out, has one electric overhead crane, railways, etc., one 10-ton and one 4-ton cupola, with their spouts connected so that metal can be run into the same ladle if required, and a Macdonald No. 12 moulding machine operated by compressed air.

Boiler Shop.—This is a square building measuring 250 feet, in five bays. Each bay is served by an overhead electric crane, and in addition there is a large number of wall jib-cranes.

The flanging presses include one 350-ton, one 130-ton, one 120-ton, two 200-ton, two plate-edge planing machines with 20 feet gap, four hydraulic riveting machines 8 feet by 10 feet 6 inches gap, one Campbell and Hunter horizontal boiler drilling machine with rotary table, Wicksteed hack-sawing machine for trimming the edges of flanged plates, etc., and electric welding plant.

The work undertaken includes boilers for steam road-wagons, tractors, traction-engines, road-rollers, portable engines, Tanks, steel bodies for wagons, locomotive boilers for outside firms, the "Spearing" water-tube boiler and superheaters.

Wood-Working Departments.

Thrasher Erection Shop.—The finished parts are drawn from stores, which extend the full length on one side, and assembled on the thrasher. The latest improvement in the "Clayton" thrashing machine is the fitting of self-aligning ball-bearings throughout.

Thrasher Paint Shop.—In this department thrashing machines, chaff-cutters, etc., are finally tested and painted ready for dispatch.

Thrasher Machine-Shop and Tool-Room.—All thrasher parts are machined here and delivered into the stores for stock.

Saw Mill.—Here all material for thrashers, chaff-cutters, and wagon bodies, is prepared. The equipment includes circular and band-saws, a dimension saw by Robinson and Son, Rochdale, and an end-tenoning machine which will take material up to 12 inches by 6 inches; planing, morticing and spindling machines, a spoke-turning machine. All machines are driven by independent motors. The dust and shavings are carried by suction ducts direct to the boiler house.

TITANIC WORKS.

Oil-Engine Machine Shop.—This department is engaged solely on the machining of parts for the "Clayton" crude-oil engines of which large numbers are exported annually, being valveless and extremely simple in design. It is specially suitable where native or unskilled labour is employed. The top end of this shop is set aside for testing, each engine undergoing a thorough brake test, and in addition an indicator test.

Oil-Engine Erecting Shop.—The assembling of oil-engines is carried on in this shop.

New Works.—This is a building measuring 1,000 feet long by 75 feet wide, having a gallery on either side, and is set aside solely for the manufacture of Clayton steam and electric road wagons. Modern mass production methods are adopted. The plant includes Churchill and Norton grinders, lathes, Dickinson's horizontal boring machines, Smith and Coventry milling machines, Herbert's vertical milling machines, Wallwork's gear cutter, Darling and Seller's bevel-gear slotting machine, and the lighter machines, lathes, vertical drills, saws, slotters, broaches, etc., on the gallery.

THE CLAYTON FORGE.

Erected in 1916, these works are amongst the finest and best equipped in the country. There are two main buildings, each measuring 350 feet by 120 feet wide with a 35-foot passage between. Each shop is served with a narrow-gauge railway.

The work undertaken includes steel forgings up to 30 cwt. and drop-stampings up to 5 cwt. in weight for railway rolling stock, motor-vehicles, road transport engines and wagons, oil and gas engines, etc., axles, crank-shafts, fly-wheels, gear blanks, connecting-rods, etc., etc.

Main Bay in Hammer Shop.—This building is set aside for the heavier work, and is furnished with a 5-ton overhead crane and served by a light narrow-gauge railway. Steam hammers up to 3 tons by Massey, each hammer with two Direct Gas Firing Co.'s heating furnaces, and two jib-cranes. A Cochran vertical waste-heat boiler works in connexion with each furnace. All the steam required to operate the plant is obtained from sixteen waste-heat boilers (eleven Cochran, three Blake vertical, and two Clayton and Shuttleworth loco. type). The heavy drop-stamps range from 80 cwt. to 50 cwt. by Massey and Bretts; each is complete with furnaces, waste-heat boiler, cranes, hydraulic presses from 150 tons to 400 tons capacity, hand-presses, etc. Hydraulic power plant pumps, air-compressors, etc.

Drop Stamping Shop.—This shop contains the lighter types of drop-stamps arranged in batteries, not singly. They range in size from 30 cwt. to 5 cwt. by Brett, and are fitted with friction lifters. Steam-hammers by Davis and Primrose, flashing presses by Hands. Each battery is complete with furnaces, waste-heat boilers, presses, etc. Additional smaller presses, furnaces, grinders, etc.

Heat Treatment Shop.—The top end of the lighter drop-stamping shop is set aside for heat treatment and oil toughening. It contains 5 hard fuel muffle-furnaces by the Direct Gas Firing Co., one of the bogie type. The oil-quenching tanks are arranged close to the furnace doors with circulation and cooling equipment and oil-

cleansing arrangements. The necessary equipment for tensile tests, Brinell and Izod tests, is in an adjoining building.

Die-Cutting Shop.—The shop measures 350 feet by 50 feet and is served by a 5-ton overhead electric crane. It contains planers by Woodward and Rowell, Redman planer, Stirk lathes, Mitchell new model lathes, Selson slotters, Jackson's die-sinkers, shapers, boring mills, saws, drills and grinders. The lower end contains a tool room, inspection department, and bar store.

Abbey Works.

Rolling Stock Departments.—These buildings, measuring 500 feet by 450 feet, were built during the War as aeroplane erecting shops, but have since been equipped for the construction of all classes of rolling stock—Pullman cars, passenger coaches, goods wagons, etc. Hydraulic and compressed-air services are installed throughout the buildings. An electric traverser having 70 feet span, by Cowan and Sheldon, extends the full length of the shops on the river side and will be used for transferring vehicles from the various bays or into a siding leading to the main lines.

The following shops will next be seen: *Pullman Car Shop, Wagon Erecting Shop, Wagon Repair Shop, Carriage Repair Shop, Paint Shop.*

Underframe Shop.—This bay is served by two overhead 5-ton electric cranes by Vaughan; riveting machines by Musgrave.

Bar Preparation Shop.—The bay is traversed by two Vaughan overhead electric cranes. It contains Wilkins and Mitchell's milling machines with fixed and movable heads, eight head-beam driller, 36-spindle drill, punching and shearing machines, saws, presses, etc.

Machine Shop. — The plant here comprises lathes, milling machines, grinding machines, drills, planers, slotting machines, shapers, screwing machines, etc.

Wood-Working Shop.—This contains moulding machines, band and circular saws by Robinson, dimension saw, Sagar sand-papering machine, drilling and boring machines, etc.

Finishing and Polishing Shop.—Fittings for Pullman cars, passenger coaches, etc. are finished, polished, etc., in this shop.

Canteen.—There is a large well-equipped canteen for work-people, staff and managers.

Huts for Workers.—To overcome the housing shortage, a number of huts in which German prisoners were housed during the War have been converted by Messrs. Clayton and Shuttleworth into living quarters for married workmen.

MESSRS. RICHARD DUCKERING, WATERSIDE WORKS, LINCOLN.

These works were started in 1845 by Mr. Richard Duckering, for the manufacture of kitchen ranges and agricultural implements, and he was followed by his son, Mr. Charles Duckering, who retired from the business in 1912, and died five years later. Mr. Richard Duckering (grandson of the founder) took over the business in 1917, and early in the present year turned it into a limited liability company.

From the beginning, the foundry has formed the chief portion of the business, and is at present being extended to meet the constantly increasing demand for high-class iron castings, for which the firm have always had a good reputation.

MESSRS. PENNEY AND PORTER, LINCOLN.

This business is an amalgamation of the two original firms of Penney and Co., Ltd., City Iron and Steel Works, established in 1868, and Porter and Co., Gowts Bridge Works, established in 1855. In 1919 the present title of the firm was adopted.

The business carried on is that of general engineering, and the comprehensive lines of manufacture include gas-holders and tanks, constructional work, coal-gas plants, corn and gravel screens, and seed-dressing machinery. Machinery for treating flax seed and fibre,

acetylene plants for welding and lighting, disintegrators, water-tube boilers, searchlights and steel, gun-metal and iron castings. At the present time the Company is engaged on the manufacture of marine and stationary oil-engines, of their own design.

The various departments consist of the pattern shop, foundry, machine and fitting shop, welding shop, plating shop, joiners' shop, screen shop, and blacksmiths' shop.

The Company also has another foundry at Saxilby (6 miles distant from Lincoln). The number of employees is about 300.

MESSRS. WILLIAM FOSTER AND CO., WELLINGTON FOUNDRY, LINCOLN.

This business was established by William Foster in the year 1856. Two years before that date he had commenced his business career as a flour miller on the banks of the River Witham, at a time when England was in the throes of the Crimean War, but following the wave of engineering development which began at that period, the flour-mill was converted into a modest engineering establishment, thus forming the foundation of the Wellington Foundry. Shortly after the death of William Foster, in 1876, the business was converted into a limited company, and eventually, owing to its expansion, a new and more commodious factory was erected at New Boultham, the business being finally transferred thereto in 1899.

It is readily evident that no better locality could have been selected from the point of view of transport facilities, the works-siding giving access not only to the Midland lines, but also to the systems of the other railway companies serving Lincoln, namely, the Great Northern, Great Eastern, and the Great Central. No better accommodation could, therefore, be desired, either for receiving raw material or for the dispatch of the manufactured article.

The Works contains its own power station, large foundry and smithy, while the boiler shop, erecting shops, machinists' departments, and the many other important departments, which are all arranged in proper sequence, are of the most up-to-date character, equipped

so as to secure the advantages of the close specialization and standardization which are demanded to-day.

Here for many years past the firm has manufactured, in ever-increasing numbers each year, portable steam-engines, steam traction-engines, road locomotives, thrashing machines, maize shellers, straw elevators, chaff cutters, traction-wagons, and other similar machinery, which have gained an excellent reputation.

In 1903 the firm commenced the manufacture of steam-tractors, and since that year have built improved models from time to time, acquiring in 1909 the rights for the basic patent for suspending the rear part of the tractor on springs placed above the axle and outside the horn plates.

For heavy haulage work, road locomotives up to 65 b.h.p. are manufactured, equipped either as ordinary haulage engines or, if necessary, with all the fittings and elaborate finish required by travelling showmen, with which profession the engines have a splendid reputation.

During the Great War, 1914–1918, the Wellington Foundry was fully occupied on munitions of war, firstly in designing and building large numbers of 105 h.p. petrol tractors and suitable wagons for hauling 15-inch howitzers at the front, and executing other important contracts. From 1915 onwards, until after the conclusion of hostilities, Tanks were built, for it was here that the designing and construction of the " Mother " type of tank took place, the Managing Director of the firm, Sir William A. Tritton (with whom in this work was associated Major W. G. Wilson), receiving Knighthood on the 13th February 1917—a fitting tribute to the predominant share he had taken in the evolution of the tanks. Here, too, were designed and constructed the " Whippet " and " Hornet " types of Tank, the former of which played an important part in the decisive battles of 1918, the latter, at the time of cessation of hostilities, not having seen service in the field.

As soon as the Tanks had proved their worth as a weapon of war at the battle of the Somme in September, 1916, larger orders than had hitherto been placed for these machines were entrusted to the firm, and in consequence a new erecting shop was built in 1917.

Simultaneously with the building of this new shop, extensive additions were made to the boiler shop, which is amply equipped with up-to-date tools, and hydraulic and other appliances, both the new erecting shop and the boiler shop being served by powerful electric and other cranes.

Additional land was also purchased as a special test field for Tanks, the terrain being made to resemble as nearly as possible the actual conditions met with in France, the field having its own railway siding. Now that the War is over, this test field will form an excellent ground on which to test traction-engines, etc.

Since the cessation of hostilities, the firm, in addition to resuming the manufacture of their normal products, namely, traction-engines, steam-tractors, road locomotives, portable engines, thrashing machines, maize shellers, chaff-cutters, straw-elevators, traction-wagons and trailers, etc., have also commenced the manufacture of compound steam-wagons, which are working with unqualified success.

During the War, owing to the demands for the Tanks, the firm employed some 2,000 workmen, and now in time of peace the number stands at about 1,000 workmen, the total area of the Works and land being about 24½ acres.

MESSRS ROBEY AND CO., GLOBE WORKS, LINCOLN.

These works, which now cover an area of over 12 acres of ground, were started in 1854. They are quite near the centre of the city, and as will be seen from the plan, are situated in Canwick Road which may be reached from the High Street by St. Mary's Street, Portland Street, or Monson Street. They were started originally on a small scale, and designed principally for the production of steam-engines and thrashing-machines for agricultural purposes, and to this branch of the trade, together with steam ploughing and the manufacture of traction engines, the first few years were devoted.

The under-type steam-engine was first made by Robey and Co., and the success of this led on to the manufacture of all classes of engines for industrial purposes, and the introduction and development in this country of the well-known drop-valve engine.

Originally a private firm, it was incorporated as a limited liability company in 1893, the present chairman being Mr. Alexander Trotter, and the managing director Mr. W. T. Bell, O.B.E., M.I.Mech.E. The works have now been fully developed to their maximum capacity, and large numbers of engines of all types are sent to all parts of the world every year.

The principal manufactures consist of the Robey "Uniflow" engine, the most economical type of engine of the present day, steam-winding engines, electric winding engines, air-compressors, over-type compound condensing engines, fitted with feed-water heater and superheater, and high-speed engines for electric generating purposes, and portable engines. It may be mentioned that these works were the first in England to be lighted by electricity, and the engines for the first electric lighting installation in London were made here.

While thrashing-machines and agricultural machines are no longer manufactured here, large numbers of portable engines, under-type engines, and locomotive and vertical boilers are dealt with every year. Road traction has always been a speciality, and dates back from the three-wheel traction engine up to the present compound tractor, traction-engines, road locomotives, and steam-wagons, and to meet the recent development and demand for the latter a separate department has been started.

This Firm was also the pioneer in this country of the manufacture of the semi-Diesel oil engine, and, as will be seen, this department is well-equipped for the production of this type of engine for either land or marine purposes, of which large numbers are being produced in powers from 6 h.p. up to 300 h.p.

The *Main Entrance and Offices* are in the centre of the Canwick Road frontage. This block consists of the board room, managing director's office, drawing office, and general office, estimating and costing offices, and secretary's office.

Proceeding from the offices through one of the stores for portable engine parts, one of the *Main Erecting Shops* is reached. This shop is used for the erection of winding engines, over-type compound superheater engines, and portable engines. It is 220 feet long by 56 feet wide, and is served by two electric cranes up to the capacity of 20 tons, and one section of it is set apart for machine-tools, the large planer having a capacity of 20 feet by 8 feet by 6 feet 6 inches, and boring machines with a capacity up to 72 inches. There are two galleries, the lower one running round the south and west side forming the *Tool Room*, which is well-equipped with die-sinking and milling machines, lathes for fine screw-gauge work, oscillating tool-grinders, surface grinders, measuring and testing instruments, including scleroscope and Brinell for hardness, and Prestwich fluid gauge. Special furnaces, both gas and oil-fired, complete with pyrometers, thermo-couples and temperature recorders for hardening purposes. The upper gallery, running along the south side only, is equipped with small machine-tools and lathes, and is set apart for the training of first and second year apprentices.

No. 2. Erecting Shop.—This is entered from the east end after leaving the previous shop, and is used for erection of traction-engines, portable engines, stonebreakers and electric winding engines. This shop is 220 feet long by 60 feet wide, and is served by two overhead electric travelling cranes, having a capacity of 20 tons. The gallery running along the south side is used for light fitting purposes. At the west end of the shop a section is laid out for machine-tools, lathes, boring machines and planers, these being driven by electric motors.

Oil-Engine Department.—This consists of two portions, one part having a main bay 160 feet long by 80 feet wide, where the executive offices of the department are situated. It is served by an overhead electric travelling crane, and is laid out with modern machine-tools, including internal and external grinding machines for cylinders and pistons, vertical and horizontal machines, high-speed drills and high-speed lathes.

Communicating with this bay is the *Erecting Shop* which is 200 feet

long by 42 feet wide, where both land and marine engines are erected. The *Testing Bays* are at the east end of the shop, and are equipped with dynamometers and all necessary appliances for testing the largest size of engines.

Packing Dock.—This is reached after leaving the oil-engine testing department. The dock is 70 feet long by 40 feet wide, fitted with overhead electric crane. Adjoining this is the *Loading Dock*, 78 feet long by 24 feet wide, and equipped with overhead electric travelling crane, and in direct communication by full gauge railroad with the main line and sidings.

Machinery Stores and Pattern Shop.—The machinery stores are under the same roof as the loading dock, and are 150 feet long by 60 feet wide. In normal times stock engines are stored here, including portable and auxiliary engines, and all sizes of high-speed engines up to 7 inches stroke. Immediately above these stores and occupying the same floor space is the pattern shop, which contains modern and up-to-date wood-working tools.

Passing out of the machinery stores, the route continues through the yard, passing the *Paint and Lagging Shop* which is 120 feet long by 80 feet wide, and

The *Automatic Machine Shop*, containing a large number of automatic, turret and capstan lathes, milling and vertical boring machines, etc. On the right the *Brass Foundry* is passed, this being 120 feet long by 42 feet wide, fitted with five furnaces and equipped to deal with the whole of the brass work required in the firm's manufactures.

Fixed Engine Erecting and Machine Shop.—This is 350 feet long by 125 feet wide. The *Erecting Bay* is 350 feet long by 37 feet wide, and is served by five travelling cranes with capacities of 10 to 20 tons. In this shop the Uniflow engines, large winding engines, and air-compressors are erected, the section at the north end of the shop being devoted to smaller auxiliary engines and high-speed vertical engines. The heavy machine-tools in this and the adjoining bay include large facing lathes, fly-wheel lathes, capable of turning wheels up to 24 feet diameter, large standard planing machines, side planers, and special boring machines arranged for boring the

main bearings and crosshead slides of horizontal engine beds at one setting.

In addition to the above the shop is well equipped with modern horizontal and radial drills, shaping and slotting machines, gear-cutting machine, and a 110 ton hydraulic press. An off-shoot in the west end of the shop contains a 30-ton power driven tensile testing machine, and a gallery which forms the shop *Drawing Stores*.

Galleries are arranged above the erecting and machine shops for brass finishing, assembling engine details, and for light machine-tools, including several spiral gear-cutting machines made by the firm.

Smith's Shop.—This is 150 feet long by 155 feet wide, having the usual smiths' fires, five Brett drop stamps up to 25 cwt., trimming presses, eight steam-hammers up to 50 cwt., three oil and coal fired furnaces with boilers, and one Bogie annealing furnace. Three bolt and nut machines, set of angle-bending rolls, one band-saw, bar-cutting machine, drilling and screwing machines, driven by motors.

Proceeding to the foundry, the *Boiler Shop*, 340 feet long by 155 feet wide, is passed on the right. This contains two sets of hydraulic pumps and accumulator, 100-ton and 200-ton hydraulic presses, 150-ton hydraulic punch, hydraulic riveters, plate-rolls, shearing machines, high-speed drilling machines, oil-fired rivet furnaces, coal and oil-fired furnaces, and electric and acetylene welding and cutting plants. The shop is served by one 20-ton electric and eight 6-ton hydraulic cranes.

Foundry.—This is 215 feet long by 160 feet wide, and has three cupolas to melt 1, 3, and 5 tons per hour. The blast is provided by a motor-driven Sturtevant Fan, and the cupolas are charged from an overhead platform with hydraulic truck hoist. There are four core-ovens fired by coke, and four fired by gas from gas-producers. This shop is served by three electric travelling cranes, 15, 20, and 25 tons.

Power House.—The power house is 150 feet long by 40 feet wide, and is served by an overhead crane. There are two water-tube boilers fitted with chain-grate stokers, coal elevator, economizers,

and constructed for a working pressure of 220 lb. and provided with motor-driven induced fan-draught, the feed-pumps taking their suction from the hot-well of each engine. The two boilers are capable of evaporating 32,000 lb. of steam per hour, each being provided with feed-water filter and water-meter.

The generating plant consists of two generating sets and one air-compressor for supplying the compressed air, which is in use all through the works.

The larger generating set consists of the firm's own type of Uniflow engine, having a capacity of 1,250 h.p., the cylinder being 35 inches by 40 inches stroke and running at 120 r.p.m. Mounted on the shaft is a direct-current generator having a voltage of 220–230 volts.

The smaller engine is of the same type having cylinder 29 inches diameter by 33 inches stroke, and running at 140 r.p.m. with generator mounted on the shaft with the same voltage as above.

Each engine is fitted with forced lubrication, shaft-governor, oil-separator and condenser, the air-pumps of which are driven in each case from the engine crank-shaft.

Water, steam, and recording wattmeters are provided, also pressure recording apparatus. A CO_2 recorder is fitted so that the flue gases from either boiler can be analysed whenever desired.

A compound steam-driven two-stage air-compressor is included having steam-cylinders 13 inches and 23 inches, and air-cylinders 23 inches and 14 inches with a common stroke of 36 inches for delivering air at 80 lb. pressure, the steam-cylinders being fitted with the firm's well-known drop-valve gear, and the air-cylinders with the Robey light automatic disk-valves, and fitted with unloading device.

Steam-Wagon Department.—This department, which is situated on the north side of the main works, is entirely self-contained and solely devoted to the manufacture of the new Robey 5-ton steam-wagon, and consists of two large bays, one 290 feet long by 60 feet wide, and one 290 feet long by 78 feet wide. The former is at the present time being equipped with the most modern machine-tools, a large number of which are already installed, which have been specially selected for the mass production of the steam-wagon

details; this bay, when completely equipped with the machines which are at present on order, will be able to deal with the whole of the machining for the steam-wagon, special jigs and tool equipment having been designed to procure rapid output and interchangeability.

At one end of the machine-shop bay there is a capacious store, from which every part in connexion with the production of the steam-wagon is drawn, no parts whatever being issued to the erectors until they have passed through the inspection department and into this store.

The detail assembling is carried out on galleries which overlook the machining bay, and these galleries are equipped for the assembling of units on a large scale.

The Assembling and Erecting Bay is 290 feet long by 78 feet wide. The assembling of the various units of the steam-wagon takes place at one end of this bay, and the wagon is gradually completed as it nears the other end, at which there is a large test-shed for testing the steam-wagon engines before the wagons are given a running test on the road. At the end of the erecting bay, the bodies are fitted, the wagons finally painted, and equipped ready for delivery.

MESSRS. RUSTON AND HORNSBY, LINCOLN.

By the amalgamation, in 1918, of Ruston, Proctor and Co., Ltd., of Lincoln, with Richard Hornsby and Sons, Ltd., of Grantham and Stockport, the name became Ruston and Hornsby, Ltd.; both companies were pioneers in the engineering industry, and both had attained a world-wide reputation.

RUSTON, PROCTOR AND CO.

In 1857, the late Mr. Joseph Ruston became a partner in the small millwrights' business in Lincoln of Burton and Proctor, which then became known as Ruston, Proctor and Co., and later, in 1889, was converted into a limited company, Mr. Joseph Ruston being the chairman until his death in 1897. The business extended continually

and in 1918 the works covered nearly 100 acres with over 8,600 employees.

The firm made its reputation on agricultural engines and thrashing machines, fixed steam-engines and boilers, and in 1876 began building steam-navvies, of which the present Company is the largest and most important constructor in the kingdom. Later, oil-engines were added and a new type developed in 1909, in which the fuel is forced through a highly-efficient mechanical atomizer into the compressed charge. This again is now succeeded by a cold starting type, capable of using any crude or residual oil, and offering the same economy as the Diesel engine, without the complication of the air-compressor.

Gas-engines are also a speciality, together with gas-producers, for the utilization of material hitherto considered useless as fuel, such as general sawmill and other waste, nut shells, plum stones, sugar-cane refuse, cotton seed, and olive residue.

Another speciality is an exhaust-heat boiler, by which the waste heat from the gas-engine can be used for making steam for heating purposes.

The Company also makes steam and oil road-rollers, oil locomotives, and centrifugal pumps. It has developed an extensive trade in maize-shellers, thrashing machines, clover-hullers, baling presses, rice-hullers, and so on.

RICHARD HORNSBY AND SONS.

These works were commenced by Richard Hornsby in a small smithy on the Great North Road at Grantham in 1815. Small agricultural machines were made, worked by horses or by hand, and in time agricultural steam-engines, thrashing machines, and elevators were added. In 1851, at the Great Exhibition, the Hornsby portable steam-engine took the first prize, and in 1859 the firm introduced into their ploughs the convex breast or mould-board, which at the time was a new principle in design. Mowers, reapers, and self-binding harvesters were included in their manufactures, and these last still retain their position in spite of American competition.

In 1879 the firm was incorporated, and in 1901, when the oil-engine was emerging from the experimental stage, the Akroyd-Stuart patents were secured by the Company, and the manufacture of the Hornsby-Akroyd oil-engines commenced, which, rapidly taking a leading place, established the oil-engine, as a prime mover, all over the world.

In 1905, the Government offered a prize of £1,000 for a military tractor that would run 40 miles, carrying its own fuel. This prize, and a bonus of £180 for exceeding the requirements, was won by the Hornsby tractor with a two-cylinder Hornsby oil-engine. Immediately after the competition this prize tractor was fitted in the place of wheels with a chain-track, which was invented by Mr. David Roberts, the Managing Director of the Company, and became the " caterpillar," so nicknamed by the soldiers during its trials at Aldershot, and a forerunner of the now famous Tanks.

In 1906 the firm of J. E. H. Andrew and Co., Ltd., constructors of the " Stockport " gas-engine, and the earlier " Bisschop " engine, which was one of the first English gas-engines to be sold, was amalgamated with Richard Hornsby and Sons, and the Stockport works added to those of Grantham. By 1918 the Company employed 3,000 men, with works covering 80 acres.

1. *The Iron Works.*—For the manufacture of oil-engines, gas-engines, traction-engines and road-rollers, portable and semi-portable steam-engines, oil-well drilling engines, oil-locomotives, pumps and corn mills.

The Machine Shop at these works consists of nine bays covering an area of 94,000 sq. ft., and divided into No. 1, 2, and 3 Turneries. No. 1 Turnery is known as the Heavy Machine Shop, dealing with the machining of engine-beds, cylinder-heads, crank-shafts and connecting-rods. This Turnery contains special machine-tools of the firm's own design for the boring and facing of oil-engine beds. The crank-pins are turned in a Gardner's largest size crank-pinning machine. No. 2 and No. 3 Turneries are known as Light Machine Shops, in which details are manufactured for standard oil- and gas-engines, and portable and traction engines. The main feature is the grouping of various classes of machines, which increases the output

with the minimum amount of transport. Jig and tool stores have been recently erected in No. 2 Turnery on up-to-date lines. The machine tools in these turneries are all of modern design by the leading makers. The brass-working machinery and the semi- and full-automatic machines are arranged in galleries, running the length of the main machine-shops.

The Grinding Shop is situated in one of the machine bays and consists of universal plain surface and internal grinders, the largest being a 36-inch by 192-inch electrically-driven plain grinder dealing with crank-shafts, etc.

The finished part stores are situated below the turret and automatic gallery.

2. *The Wood Works*, covering 18 acres, are set apart for the manufacture of thrashers, bruisers, sifters, clover-hullers, chaff-cutters, rice-thrashers, rice-hullers, maize shellers, elevators, self-feeders, baling presses, and traction-wagons, and an agricultural tractor, which is being produced on mass-production lines and in very large quantities. The machines, and their parts, are all painted and varnished by the dipping process, the dipping tanks being of a size to take the largest assembled parts with the greatest ease. The main turnery covers 27,180 sq. ft., and is filled with the most up-to-date machinery that it has been possible to obtain.

3. *The Motor Works*, where the Ruston-Hornsby 16–20, 4–5 seater touring car is built, is a special product of the War. Originally used for the storage of agricultural machinery, when the War broke out this store was turned into an aeroplane works, which, extending with mushroom-like rapidity, was turning out 25 to 30 engines and 30 aeroplanes every week. Much of the machinery for this was supremely well fitted for car production, and cars are now being turned out in the same efficient and rapid fashion as the aeroplanes.

The total area of the Machine Shop alone is 47,700 sq. ft., whilst the Tool Room (which supplies all the works) covers 10,800 sq. ft. There are spacious erecting and dismantling shops and specially erected buildings for the heat treatment of metal.

These works are able to turn out 50 cars per week, rising to 100 very shortly. A special feature is a battery of machines for all types of gear cutting. The Mess Room is able to seat 1,060 employees at once.

4. *The Boiler Works.*—This is one of the largest and best equipped works for the manufacture of Lancashire, Cornish, flue or tube, dryback, vertical, water-tube and exhaust-heat steam-boilers, and portable multitubular boilers for oil-well drilling, and structural work generally in the United Kingdom. It is equipped with the most up-to-date appliances, which enable the firm to produce boilers ranging from the small boiler for steam-wagons to large Lancashire boilers, 30 feet by 9 feet 6 inches and marine boilers to 10 feet by 9 feet 6 inches. These works can turn out one boiler every working hour and a quarter.

The 2,000-ton press permits the flanging of plates up to 9 feet diameter; multiple drillers are much in evidence, and there is a special machine which enables circular shells up to 9 feet 6 inches diameter to be carried on a rotating table for the turning up of the ends, and on the same setting the holes for longitudinal joints can be drilled.

Welding is carried on to a large extent by electric oxy-acetylene and oil-heating systems. A special feature of the small boilers is the extensive use of pressings for fire-boxes, thereby eliminating joints. Angles and sections are cut to length by means of a high-speed cold saw, and a circular shearer enables plates to be sheared to size with surprising accuracy.

5. *The Navvy Works, Spike Island.*—For the construction of the well-known Ruston Excavators, comprising crane type or full circle models, Nos. 5, 12, 20, and 30, the weights of which range from 61 tons to 120 tons, also the No. 30 railway type of steam-shovel, weighing 80 tons. The indicative numbers refer to the bale pull or cutting effort in tons. These machines are suitable for all classes of excavation work from trench excavation up to the excavation of heavy iron-ore in open workings; also for all general contract work.

The machines are usually arranged for travelling on rail wheels,

but some of the models are mounted on road wheels or caterpillar travelling gear to suit working conditions. To carry out the removal of overburden or spoil from mineral banks, transporters are supplied to work in conjunction with the excavators.

The power of these five Works is generated at two separate power stations. One station is at the Iron Works, with an output of 1,500 kw., developed by four "Ruston" horizontal drop-valve steam-engines. In addition is a sub-station with a 500 kw. rotary converter running from the Lincoln Corporation Electric Supply. Another station is situated at the Wood Works, generating 2,100 kw. developed by five engines of various makes and types, including a "Ruston" four-cylinder horizontal gas-engine. There is also a sub-station with a 500 kw. rotary converter and a 1,000 kw. static transformer for low tension a.c. driving, generating power for the plant at the Navvy Works and the Foundry adjoining.

The Forge Department and Smith Shop, which feeds all the five works, is situated at the Iron Works, and in addition to the many smaller powered drop-hammers, possesses a battery of 3, 4, and 5-ton drop-hammers, also several forging hammers, including a 2-ton Nasmyth.

The Foundry for the supply of soft iron and malleable iron castings was situated entirely at the Engine Works, but owing to increased demands upon output, it has been necessary to build a second and more modern foundry near the Navvy Works. This new foundry is specially equipped with moulding machines, and covers 60,000 square feet. It is provided with travellers, Morris runways and electric runway systems. The latter are used for the transport of castings and sand, and are connected with a new fettling shop now in course of construction. Further extensions are in progress to cope with the castings required, including a new shop which will cover an area of 25,000 square feet.

A new and entirely modern *Pattern Shop* is also situated near the new foundry, from which shop are supplied the patterns, by the most up-to-date methods, for all the works.

The machine shops at the various works are laid out upon the

" group " system, thus giving the most productive effort with the minimum of transportation.

The fitting and erecting shops, in all cases, are in immediate proximity to the machine shops, and much thought has been expended in making these suitable for the work for which they are required. Generally, the shops are so arranged that the engine or machine is passed from the test-bay to the dismantling and painting shops, and thence to the packers, with the minimum handling.

Loop lines from the main lines of the Great Northern, Midland, Great Central, and Great Eastern Railways, run into all the five works for the bringing in of raw material and the dispatch of machinery, whilst inter-communication between these Lincoln works is maintained by an efficient service of motor- and steam-lorries.

Grantham.—The works, covering 75 acres, are laid out on similar lines for the manufacture of the Hornsby oil and gas-engines and anthracite gas-producers, and also for the Hornsby harvesting machinery, such as binders, mowers, reapers, trussers, drills, and ploughs.

Stockport.—These works are entirely devoted to the manufacture of the Hornsby-Stockport gas-engine, which is a direct evolution from the earlier Andrews-Stockport engine mentioned in the preface.

The Ruston-Hornsby works are also equipped with efficient chemical and metallurgical laboratories for controlling the quality of materials used in manufacture.

FRODINGHAM IRONSTONE MINES.

The Frodingham Ironstone Mines are situated in the Lincolnshire parishes of Frodingham, Scunthorpe, Ashby, Crosby, and Appleby, and are adjacent to the Great Central Railway, midway between Doncaster and Grimsby. They were opened out in 1859 by the proprietor, Rowland Winn, Esq., of Nostell (Yorks) and Appleby (Lincs.), who became the first Baron St. Oswald in 1885, but they are now the property of the Frodingham Ironstone Mines, Ltd., formed 1st July 1918.

The mines, which give employment to about 500 men, are the most extensive of their class in England and have an output of 1,000,000 tons of ironstone per annum. The faces, remarkable for their length and straightness, are connected together, to the Great Central Railway, and to the various works of the district by about 25 miles of ordinary-gauge railway.

The stripping, or laying bare of the ironstone, is in the main done by mechanical means, and the machines in use for this purpose are: one Berry Excavator and Transporter, two Ruston Navvies with transporters, four Ruston long jib crane navvies, and five Wilson 70-foot jib grab cranes. Much of the ironstone is got by Ruston-Hornsby steam-crane navvies and, at the present time, one No. 30 and six of the No. 20 pattern are in daily use, but about 100 men are still employed in hand-getting.

The ore is drilled and blasted before being filled. The drilling is, for the most part, done by hammer-drills driven by compressed air. On the Crosby Face a "Cyclone," which drills a hole 6 inches in diameter, does very useful work. The explosive used is ammonal No. 5.

The drainage necessitates the removal of enormous quantities of water, and this is effected at pumping stations conveniently situated and by means of many electrically-driven centrifugal pumps.

The haulage and transport is done by means of 15 locomotives and 700 wagons. The chairman of directors is the Hon. G. W. Winn, and the resident manager is Mr. R. E. Westwood.

MESSRS. JOHN LYSAGHT, SCUNTHORPE.

The chief features of this important undertaking may be grouped under the following headings.

Ironstone Mines.—The native stone is worked by open quarrying; the equipment comprises compressed-air apparatus for drilling, together with electrically-driven pumping machinery, the ironstone being wrought by six "Ruston" mechanical steam-driven navvies, capable of dealing with 8,000 to 10,000 tons per week of raw stone.

Coke-Ovens.—Ninety-six in number of the Semet-Solvay regenerator type, with by-product recovery plant attached. The plant is complete with all the latest devices. The by-products recovered are tar, sulphate of ammonia, and light oil.

Blast-Furnaces.—Five in number (four in operation, one in course of construction), all fitted with the latest type of mechanical charging devices, employed chiefly in the smelting of Lincolnshire low-grade ores. The gas is rough cleaned for stoves, boilers, and gas soaking pits. The final cleaning is effected by Theisen washers for gas blowing and power engines.

Power House.—Two "Galloway" horizontal gas-driven blowing engine sets, 35,000 cubic feet of free air per minute. One "Lilleshall" horizontal steam-driven blowing engine set, 20,000 cubic feet of free air per minute. Four "Nuremberg" horizontal gas-driven blowing engine sets, 20,000 cubic feet of free air per minute. Two "Nuremberg" horizontal gas-driven power generating sets, each 600 kw. direct current 500 volts. Two "Belliss and Morcom" turbo-generators, each 750 kw. direct current 500 volts. Two "Daniel Adamson" turbo-generators, each 1,500 kw. alternating current. One "Westinghouse" vertical gas-driven power generating set, 670 kw. alternating current 500 volts. All are commanded by an electrically-driven overhead crane.

Boiler Plant.—Twelve Babcock gas-fired. Four Galloway boilers, 160 lb. high-pressure steam per square inch.

Steel Furnaces.—Six in number: Four "fixed furnaces," 50 tons capacity; one "tilting furnace," 190 tons capacity; one "fixed furnace," 90 tons capacity; and one 400 tons tilting metal mixer. All are commanded by electrically-driven overhead cranes, and all the materials are charged by mechanical means.

Rolling Mill.—Made by Lamberton and Co., with roller gear and cutting arrangements complete, comprising cogging and finishing mills, chiefly used for the production of tinplate bars, billets and rails.

Soaking Pits.—Four gas-fired soaking pits absorb the waste-gases from the blast-furnaces and coke-ovens, for heating up steel ingots prior to rolling. All are commanded by electrically-driven overhead cranes.

Six coal-fired soakers are commanded by electrically-driven overhead strippers and chargers.

THE FARRAR BOILERWORKS, NEWARK-ON-TRENT.

This firm was founded by the late Mr. Alfred Farrar, on the present site, rather over thirty years ago, principally for the manufacture of vertical and other types of boilers. The works are picturesquely situated, high up on the banks of the River Trent, and unlike the majority of engineering works, command a fine uninterrupted view of verdant country. But they are also well placed for the economical and expeditious handling of large shipments, having a siding in direct communication with the Great Northern and Midland Railways, whilst there is also a good river service to the ports of Hull, Grimsby, and Goole, which can be reached by lighter in a few hours.

The works were purchased by the present Company, of which Mr. Louis W. Smith is the managing director, from the trustees of the late Mr. Alfred Farrar in December, 1912. During the last seven years, the Company have added considerably to the plant and buildings, so that they can undertake, in addition to their speciality of vertical cross-tube boilers, marine boilers, welded tubular boilers of the fire-engine type, Cornish boilers and colonial type boilers, air-receivers, etc. They are also extensively engaged in the designing and manufacture of gas-mains (made of riveted plates), mooring buoys, steam-jacketed vessels, and pans for food production, concrete mixers, concentrators used in the manufacture of cattle foods and manure made from fish offal, and they also undertake forgings weighing up to 4 cwt.

The works, which at present occupy about 2 acres of land, comprise a smithy, platers' bay, riveting bay, drilling bay, machine shop, and fitting shop. The smithy is equipped with two electrically-driven pneumatic hammers of the latest type, and is used for angle-smithing as well as small forgings. Other installations of plant which have recently been made include an electrically-driven Asquith

radial drilling machine, a punching and shearing machine, electric hoists and cranes, etc. Special attention has been devoted to modernizing the hydraulic and pneumatic plant, which are important factors in the efficient and cheap production of boilers.

The driving power is chiefly electric, the current being supplied by the firm's own generating plant, which consists of two Crossley gas-engines, using suction-gas, one of which is coupled direct with a Mawdsley generator. Other tools are driven direct from a twin gas-engine by Crossley. There is also installed in the same engine-house a Broom and Wade air-compressor, a set of hydraulic pumps, and a Robey 2-cylinder oil-engine (Bollinder type), which is coupled direct to a dynamo, to supply current for lighting, etc.

Messrs. Farrar have recently purchased 5 acres of land adjoining their works, and contemplate building several new shops in the near future. Work has already commenced on two further bays, 180 feet long by 50 feet and 38 feet span respectively, which will be used for riveting and fitting shops, and cranes up to 20 tons capacity are being installed in these shops.

MESSRS. A. RANSOME AND CO., WOOD-WORKING AND CASK-MAKING MACHINERY WORKS, NEWARK-ON-TRENT.

This Company took over Messrs. Samuel Worrsam and Co.'s wood-working machinery business at Stanley Works, Chelsea, in 1868, and was founded by the late Mr. Allen Ransome, of Ipswich, who died in 1913. The branch foundry business of Ransome, Josselyn and Woods, in Battersea, was formed in 1875; and was amalgamated with A. Ransome and Co. when the latter was converted into a limited liability company in 1892.

The works were moved from London to Newark-on-Trent in 1900, where a factory was erected on a site of about 10 acres, adjoining the Great Northern Railway, four sidings from which run into the works, and serve for bringing in the raw material and taking away the finished machinery. About 500 men are now employed.

This Company has been for a long time acknowledged as one of the leading wood-working and cask-making machinery manufacturers in the United Kingdom, and they have supplied their machinery to all parts of the world. The following are their leading specialities :—

1. Tree-felling and log cross-cutting machinery.
2. Horizontal and vertical log band-saw machines.
3. All types of re-sawing machinery.
4. Planing and moulding machines, specially designed for very rapid production.
5. Machines specially adapted for work on private estates.
6. Railway carriage and wagon machinery.
7. Railway sleeper and key machinery.
8. Machinery for joiners and cabinetmakers.
9. Electrically-driven wood-working machinery of all descriptions.
10. Pneumatic apparatus for the automatic collection of wood refuse.
11. Accessories for the saw-mill and wood-worker.
12. Machines for making casks, barrels, etc., of all types and sizes.

In 1903 the Company took up the manufacture of mechanical stokers for the Underfeed Stoker Co., Ltd. Owing to the successful application of the underfeed type of stoker, the trade grew quickly, and in order to cope with the demand the Company have twice extended their foundry, and in 1911 built a new fitting and erecting shop, which again was extended in 1912.

Existing steam-boilers vary in design, age, size, and disposition, while boilers of new types and of greatly increased capacity multiply as encouraged by the development of mechanical firing. The Company, therefore, manufacture stokers of several types, a brief description of which, together with other coal and labour-saving appliances, is given in the following list :—

Class B.—Underfeeding by steel worm. Applied to internally-fired boilers.

Class E.—Underfeeding by a reciprocating sliding bottom. Distribution by moving firebars. Automatic ash-discharge. Applied to water-tube boilers.

Class A.—Forced draught travelling-grate stoker, for the combustion of low grade and low volatile fuels. Applied to water-tube boilers.

Class A. (self-contained).—A travelling-grate stoker which brings together in one unit the scattered machinery of fans and driving mechanism.

Ash-Conveyor.—A water-trough ash-conveyor, which forms a real solution of the automatic ash-handling problem.

Air Heater.—A plate heater for transferring heat from the waste gases to the air used for combustion.

CO_2 Thermoscope.—For determining the efficiency of combustion.

Draught Gauge.—A practical device for the boiler house.

Messrs. A. Ransome and Co. for several years also manufactured ball and roller bearings, and, owing to the Government requirements due to the War, this branch was considerably enlarged in 1915. In January 1917 a separate Company (The Ransome and Marles Bearing Co., Ltd.) was formed to take over this part of the business.

Power.—The works are driven entirely by electric power generated on the premises, the supply being at 200 volts direct current. The power equipment consists of two Stockport gas-engines, each of 100 h.p. and three National gas-engines of 100, 130, and 150 h.p. respectively. The gas supply for these engines is from two Dowson-Mason gas-producers.

All the workshops are built on the ground floor and are fitted up with the latest labour-saving machine-tools and with every modern device for economizing labour and cheapening production. There is a complete system of 2-foot gauge tramways throughout the works.

Every part of the offices and works is in touch with all the others by means of a complete telephone system, connected with the Post Office Telephones.

Pattern Shop and Case-making Department.—This shop is 100 feet long by 60 feet wide and is equipped with machinery of the Company's

own manufacture. It also has a pneumatic installation for the removal of wood refuse.

Pattern Store.—In this store, where there are over 30,000 patterns, the card index system is used.

Smiths' Shop.—In this shop there are thirteen fires, which are supplied with the necessary blast from one high-speed centrifugal blower. There are also two electrically-driven pneumatic hammers of 10 and 3 cwt. respectively.

Foundry.—The foundry, which covers an area of 31,000 square feet, is divided into three bays, one of which is equipped with the latest pneumatic moulding-machines. Attached to this bay is a fitting shop and stores for pattern plates. The middle bay is served by a 6-ton overhead electric travelling crane, and the large bay has one 10-ton and one 15-ton overhead electric travelling crane. In this latter bay there is a large pneumatic jolt ramming machine. There are two large drying ovens heated by producer-gas. Two cupolas of 5 and 4 tons respectively are situated at one side of the large bay. The sand-mixing room is equipped with a centrifugal mixer, a sand-sifter, and a loam mixing-mill. A small brass foundry and core-room for small cores are situated at one side of the main foundry. The fettling department is equipped with two double-disk grinders, two rumblers, pneumatic chipping hammers and a small drilling machine for carrying out box repairs, etc. At this end of the foundry there are some special doors to allow the overhead traveller from the large bay to take heavy castings direct to the door of the machine shop.

Main Machine and Fitting Shop.—This building, which is divided into 3 bays, is 392 ft. long by 90 ft. wide. Half of this consists of a machine shop, the remainder being devoted to fitting, erecting, testing, painting and packing woodworking machinery.

The main bay, which is 45 ft. wide, is served by a 5-ton and a 10-ton overhead travelling cranes. All the machine-tools are as far as possible grouped in their respective classes. In the main bay there are planing, large shaping and slotting machines, drilling and boring machines, and heavy lathes. In the right hand bay are lathes, and in the left hand bay are the small shaping and milling machines, stud lathes, screwing machines and grinders. Attached

to the left hand bay is the well-equipped tool room. In the centre of the main bay is the inspection department.

In the fitting and erecting department the heavier machines are dealt with in the main bay, the lighter machines being fitted up in the side bays. Attached to the left hand bay are the stores for the issue of all standard bolts, screws, oil, etc. The machines, as finished, then pass on to the testing floor. This department is equipped with one 50 and one 40 h.p. variable speed motors, with shafting and a complete range of pulleys. The machines then pass on to the painting and packing department, being finally loaded up direct into railway trucks in the shop. On the right, at this end, are the receiving and dispatching office and stores for all standard saws and tools for wood-working machinery.

In the left hand corner at this end of the main shop is a department for the making up of new and repairing old band-saws of all sizes from $\frac{1}{4}$ inch up to 12 inches wide. This department is fully equipped with machines of the Company's own manufacture for the different operations of punching, brazing, tensioning, sharpening, and setting, the saws thus being made up complete from the tempered and polished steel band.

Leading out of the main shop on the right hand side is a stock-room for the smaller wood-working machines. Adjoining this is the large fitting and erecting shop for the Underfeed Stoker Co.'s mechanical stokers. The smaller bay, which is 115 feet long by 40 feet wide is for the erection of the underfeed type of stoker for Lancashire boilers and the smaller sizes of underfeed type of stoker for water-tube boilers. In the main building, which is 305 feet long by 50 feet wide, the larger sizes of the underfeed type of stokers for water-tube boilers, and also the travelling grate type of stokers are erected. All stokers are painted before being dismantled, and then they pass on to the end of the main building for packing and loading up direct into railway trucks in the shop. At this end, on the left, is a department for the collection and dispatch of all spare parts and repairs for stokers.

RANSOME AND MARLES BEARING CO., NEWARK-ON-TRENT.

"R" and "M" Bearings were first manufactured by Messrs. A. Ransome and Co., Ltd., in 1906. The original bearings were of a double type, the invention of Mr. Henry Marles. They were first used on woodworking machines, and so successful was the result that many of the leading motor-car and lorry builders adopted them as standard. On the outbreak of war there was an immediate shortage of all types of ball bearings, as the Germans held three-quarters of the British trade. Immediate steps were taken to increase the output of bearings, and many large extensions of plant and premises were carried out. An entirely separate company and organization was formed known as The Ransome and Marles Bearing Co., Ltd.

During the War the factory was engaged on the manufacture of special ball and roller bearings for such famous aircraft engines as the Clerget, Rolls-Royce, Eagle and Falcon, Hispano Suiza, B.R. 1, B.R. 2, Le Rhône, A.B.C., etc.; and for well-known motor transport vehicles of all descriptions.

Methods of Manufacture used in the "R" and "M" Factory.

1. *Steel Stores.*—Special ball-bearing steel is used, and, before being accepted, is subjected to very stringent physical tests and chemical analysis.

2. *Heavy Turnery.*—Here the larger bars are turned, inspected for flaws, ground, and parted off into blanks of the correct size.

3. *Light Turnery and Automatic Department.*—In this department the races themselves are finished and machined in the soft state. Very fine limits are adhered to in this shop, as the cost of subsequent operations is greatly increased if any inaccuracies occur; for this reason a rigid inspection is made between successive operations. Every ring is stamped in this shop with the trade mark, "R and M," and with certain reference numbers and letters which indicate

the size, and enable the Company to trace subsequently, if necessary, the make of steel, the date of manufacture, and even the machines on which the bearing was made.

4. *Heat Treatment Department.*—In this shop the rings are heat-treated and hardened, afterwards being carefully inspected for a glass-hard surface and tensile strength.

5. *Chemical Laboratory.*—Every batch of steel and bearings is tested here by chemical means. Experimental work is also carried out on the composition of materials used.

6. *Grinding Department.*—In this department the degree of accuracy and finish aimed at is seldom, if ever, attained on any other engineering product. Every part is inspected rigidly after every operation. The limits worked to are all under one-half of one-thousandth of an inch.

7. *Assembly and Final Inspection Department.*—Here all bearings are subject to a further inspection of every dimension and also for flaws and finish, before they are accepted for assembly. The balls, rollers, cages, etc., are fitted here, and the assembled article is again viewed before it is finally greased and packed. In the final operation of assembly, outer and inner races of balls must be of the correct size to within one-ten-thousandth part of an inch.

8. *Cage-Making Department.*—The "R and M" ball-cage or separator is die-cast from special white metal in this department. All cages are reinforced with steel which is cast in.

9. *Power Plant.*—Two high-speed compound vertical engines drive direct current generators of 400 and 250 kw. respectively, and a third set, comprising a triple-expansion vertical high-speed engine and generator of 500 kw., is now being installed.

10. *The Canteen.*—This was built during the War and was greatly appreciated by the workers, especially as a full night shift was running. A works' sports and social club is run in connexion, and many dances, concerts, etc., are arranged and held here.

MESSRS. RUSTON AND HORNSBY, BRADLEY'S FOUNDRY, NEWARK-ON-TRENT.

The foundry was started in a very small way in the year 1814. In 1876 it was acquired by Mr. Thomas Bradley, who was afterwards joined by Mr. William Bradley, and in 1900 they formed a limited company under the name of T. and W. Bradley, Ltd. The foundry was extended for producing general engineering castings up to 10 tons in weight.

In February of this year Messrs. Ruston and Hornsby, Ltd., purchased the foundry and are now enlarging and modernizing it for the production of castings for their gas and oil-engine business. When completed, the foundry will be about 300 feet long and 60 feet wide. It is at present arranged for floor moulding.

MESSRS. WORTHINGTON-SIMPSON. NEWARK-ON-TRENT.

The well-known firm of James Simpson and Co., Ltd., recently acquired the assets and rights of the Worthington Pump Co., Ltd., within the British Empire, the joint enterprise being since known as "Worthington-Simpson, Ltd." In the year 1790 the business was established by James Simpson in Eccleston Street, London. On the death of the founder, the business passed into the hands of his eldest son, Mr. Joseph Simpson, who was succeeded by his younger brother, Mr. James Simpson, who afterwards became President of the Institution of Civil Engineers. Under his control the business was moved in 1838 to larger premises in Belgrave Road, and subsequently to larger premises in Grosvenor Road, London. The sons of Mr. James Simpson succeeded their father, and in 1886 the business was converted into a company with limited liability. The output grew, and to meet the increasing demand, extensive new factories were built at Newark-on-Trent, and the old premises used as repair

shops. The amalgamation and change of title referred to above followed shortly afterwards. The head office of the Company is at Queen's House, Kingsway, and the new and extensive works at Newark now comprise the following buildings :—

Pattern Shop, with a floor space of 7,500 square feet, equipped with all modern appliances in the shape of wood-working machinery.

Iron Foundry, with an area of 33,000 square feet, equipped with cupolas having a melting capacity of 3, 6, and 12 tons of metal per hour, and electric cranes of from 5 to 25 tons lifting power.

Brass Foundry, with a floor space of over 6,000 square feet, with melting furnaces on the tilting principle, with a total capacity of 3,500 lb., and crane power equal to 5 tons, electrically driven.

Smith and Plating Shop, having 10,000 feet floor space, with 10, 20, and 30 cwt. compressed-air driven hammers, shearing and punching machines, and also a band-saw. Forgings, cooling towers, tanks and large fans are made in this department.

Heavy and Light Machine Shops, with a floor area of 12,000 square feet, and equipped with the latest design of heavy and light machinery suitable for the class of work, and crane power of from 3 to 30 tons capacity.

Fitting and Erecting Shops, with an area of 20,000 square feet, and with a lifting power of from 5 to 30 tons to a height of 40 feet from the floor.

Brass Finishing Shop and Test House, each occupying a space of 2,800 feet, the latter with tanks and electrical equipment to deal with motors of all makes and voltages as may be required.

Packing Stores, with a floor space of 9,000 feet, and having an overhead crane of 15 tons lifting capacity.

The works are on the Great Northern branch line from Newark to Nottingham and have sidings connected thereto for the conveyance into the works of raw materials and for the dispatch of finished goods and machinery.

The Newark works specialize in the manufacture of pumping machinery and condensing plants, and amongst the former may be mentioned the large pumping engines designed and built for the Buenos Aires Waterworks, these being Worthington engines of the

vertical triple-expansion high duty compensated type. At the present time they have going through the Newark works the whole of the pumping machinery for the New Delhi Waterworks.

Condensing plants of the largest size are manufactured at Newark, and many of the principal electrical generating stations, not only in this country but in various parts of the world, are equipped with Worthington-Simpson condensing sets. In addition to the above, the firm specializes in the manufacture of centrifugal pumps of all sizes and services; also in pumps for oil and boiler feed service.

A large amount of general engineering work is manufactured at the works, and it will be noted that at the present time they have under construction one of the largest blast-furnace gas-engine-driven blowing engines, which is being built to the order of one of the principal steel works in the Midlands.

MESSRS. MARSHALL, SONS AND CO., GAINSBOROUGH.

These works were established in 1848 and a limited liability company was formed in 1862. In 1870 the area was about 4½ acres and the number of workmen between 500 and 600. From that time up to the present day, the development and progress of the firm has been one of continued expansion, and the outbreak of war in 1914 found the firm employing about 5,000 workmen and with an establishment covering about 43 acres. The works now comprise: Britannia Works (engineering); Trent Works (wood-working); Carr House Works (finishing and dispatching); Central Power Station, Lea Road. At the present time, the number of workers is not up to the normal complement. Over 2,000 men enlisted during the war period, and about 1,000 women-workers were then employed, mainly on ammunition components work.

During the seventy-two years' activity of this firm, over 175,000 engines, boilers, etc., have been produced, and this output represents

an equivalent of about 4,000,000 i.h.p. This aggregate includes from 2 n.h.p. small portable steam-engines for driving thrashing-machines, to mill engines of 2,000 i.h.p., such as are used in industrial centres.

The firm's manufactures may be generally divided into agricultural and industrial classes. The agricultural class includes steam-engines, oil engines, traction and ploughing engines, thrashing-machines, maize shellers, elevators, tea-preparing machinery, fibre and flax machinery. The industrial class includes many types of steam-engines and boilers for driving factory machinery, pumping, &c., oil-fields power plant, road rollers, various haulage engines, oil engines, etc. This establishment, when turned over to meet war requirements, produced naval gun mountings, "Tanks," aeroplanes, military vehicles, cordite presses, chemical-making plant, field gun ammunition and components, bombs, pumps and trench warfare details, etc.

Owing to the unavoidable time-limit, the following sections of the works were selected for inspection, and the tour was made through the various departments in the order given herein.

TRENT WORKS.

To the left of the entrance of these works (which are devoted to the preparation of wood for all classes of "Marshall" manufactures and works requirements) is situated an engineering laboratory (equipped by the firm) in connexion with the Gainsborough Technical School. The experimental engine is an 8 n.h.p. girder bed type, steamed by a locomotive boiler working at a pressure of 150 lb. The engine has its valve-gear and controls so arranged that it can be worked with the high or low pressure sides as simple engines, also worked compound, condensing and non-condensing. Measuring tanks, brakes, tachometer, speed counter, gauges, etc., are provided so that all physical and mechanical effects may be demonstrated for instructional purposes. The boiler is fitted with a superheater.

The Trent Works power-house contains two "Marshall" compound condensing engines, cylinders 12 inches and 21 inches by 26 inches stroke, for 150 lb. w.p. The engines have jet condensers,

and Crompton dynamos to generate current for light and power are fitted on the engine crank-shafts. Each set will give off 125 kw. at 220 volts direct current.

In the boiler house are three 125 h.p. "Marshall-Heine" water-tube boilers, with grates for burning sawmill refuse. The refuse is carried from the sawmill by a band-conveyor, and then hand-fired to the furnaces.

The sawmill consists of two bays, each 50 feet wide by 325 feet long, with a gallery on one side. The gallery is utilized for stores, spoke-making and tool work. The mill equipment includes a Ransome band-saw for cutting up to 5 feet, log saw bench, planers, and other machines usual in works of this class. Under the mill floor is a cellar wherein are installed the electric motors driving the different machines, also the belt-conveyor system which transports the wood refuse from the machines to the boiler house.

The stores building is 403 feet by 60 feet. The ground floor is a store for thrashing-machines. The prepared wood is stored on the first floor. The gallery and roof are utilized for storage of patterns.

Every facility is provided by means of travelling steam locomotive cranes, narrow-gauge tramways, and electric shop cranes for the transport of the timber from the log stage to the finished component.

Britannia Works.

Test-Pits.—On entering these works at the No. 1 Entrance, the testing-pits for portable and traction engines and road rollers can be viewed. The building is 200 feet long by 70 feet wide and can accommodate simultaneous testing of 16 engines. It is served by an elevated electric crane, 25 tons capacity, and fitted with telescopic and swinging chimneys to connect up with the chimneys of the engines under test.

Engine Erecting Dept. 1 (*Portables, Tractions, etc.*).—This is 260 feet long by 140 feet wide, with galleries on all sides. The engine erecting is done on the ground floor and galleries are utilized for the lighter classes of machine-tool work and fitting. Electric cranes, ranging from 1 to 12 tons capacity provide ample handling facilities.

Galleries and ground floor have direct access to stores for engine parts.

Engineers' Extension—The machinery hall comprises four bays, each 350 feet long by 45 feet wide. The handling plant comprises electric overhead cranes for lifts from 1 to 25 tons. The works' 2-foot gauge tramway runs through this shop, and the track system ensures convenient distribution of material to the machines and the transfer of finished work to erecting shops and stores. Electric locomotives are employed for haulage, and horses also assist on the outdoors parts of the system.

Engine Erecting Dept. 2 (" *K* " *Bay*).—This adjoins the machinery hall, and is devoted to the erection of fixed engines. The building is 100 feet long by 40 feet wide with a 25-ton crane. Also adjoining are the test-pits for large stationary engines. Steam is supplied from two 200 h.p. "Marshall-Heine" water-tube boilers, 160 lb. w.p., and one " Galloway " boiler, 30 feet by 8 feet, for 100 lb. w.p., and boiler feed from the works' softening plant. A complete system of pressure-reduction valves and swivelling pipe-connexions ensure convenient steam supply to engines under test.

Foundry.—This is a building of three bays, each 315 feet long by 53 feet wide. Pig-iron, coke and other foundry supplies are delivered at the cupolas direct from the railway trucks, there being a siding connexion with the Great Central Railway on the east side of the works. There are eight overhead cranes electrically driven, ranging from ½ ton to 30-ton lifts. The metal is delivered from four cupolas, three having a capacity of 10 tons each per hour and one of 6 tons per hour. There are fourteen gas-fired core ovens supplied by four " Mason " gas-producers.

The fettling department is situated at the north end of the foundry. Castings are delivered from the foundry by the 2-foot gauge tramway, and they pass into the foundry yard either for storage or delivery in other parts of the works.

Old Boiler Shop.—This shop consists of five bays, each 250 feet long by 40 feet wide, and is equipped with electrically-controlled overhead and jib cranes and hand cranes. The lifting capacities range from 2 to 12 tons. The machinery comprises hydraulic riveters and presses

and pneumatic tools of the latest types suitable for the production of high-grade boiler and plating work. This department is mainly devoted to the manufacture of tubular boilers of the locomotive and allied types.

Machine Frame Shop.—This shop, which receives its wood supplies from Trent Works, is 165 feet long by 134 feet wide. In it all framework in connexion with thrashing-machines, wagons, etc., is prepared. The annexe is 68 feet long by 65 feet wide, and is reserved for the erection of hay and straw elevators.

Stores for Thrashing-Machine Components.—In this department, which is 310 feet long by 62 feet wide, components for machines are stored under a system which enables any machine or group of machines to be assembled at short notice. The components are sent by hoist to the erecting shop above.

Paint Dipping Department.—This is used for bodily dipping thrashing-machine parts. The tank contains 12 tons of paint at working level, and overhead runways facilitate the handling of the parts under treatment. The building is 60 feet long by 16 feet wide.

Pattern Shop.—This at present is a temporary arrangement located in a building 98 feet long by 50 feet wide. (The former pattern shop was at the top of Spring Gardens, and was destroyed by fire on 6th May 1914.)

Machine Paint Shop.—In this department, thrashing and allied types of machines are painted and finished. The building is 250 feet long and 60 feet wide, and comprises two floors. An overhead bridge gives connexion between the machine erecting shop and this painting department. The stores adjoining are equipped with paint grinding and mixing machinery. On the ground floor, tea machinery is packed for dispatch.

Thrashing-Machine Erecting Shop.—This is 410 feet long by 65 feet wide, in one bay, with an annexe 80 feet by 40 feet. Here all thrashing-machines are erected and completed ready for testing. It is possible to have from forty to fifty different machines under simultaneous erection in this department. At one end of the bay, electric motors and apparatus for running six machines under test at one time are arranged.

Machine Fitting Shop.—This is 365 feet long by 55 feet wide with a gallery 25 feet wide at one side and 18 feet at each end. It is equipped with two cranes (one 8 tons and one 5 tons) and a complete plant of planing, drilling, boring, turning, punching, shearing and other machines for manufacture of metal components for thrashing and tea machinery.

Machine Stores.—This building consists of three floors. The ground floor is 80 feet by 48 feet, and the first and second floors 104 feet by 49 feet. A 2-ton crane is installed and the stores are used for components for thrashing machinery and tea machinery.

Smithy.—This department consists of three bays, two 30 feet wide and one 80 feet wide, and each bay is 300 feet long. There are sixty-two smith's fires, twenty-one hammers, ranging from 1 ton to 1 cwt., five sets of drop stamps ranging from 15 cwt. downwards, nut and bolt machines and oil-fired furnaces; also scrap balling and forging furnace. The case-hardening section is placed in one corner of the smithy, and contains two coal-fired furnaces and one gas-fired furnace.

Wheel Shop.—This department is 195 feet long by 95 feet wide, and contains furnaces for heating tyres, electric welding machine, bending and riveting machines. It is equipped with two 3-ton cranes. The electric welder is capable of welding tyres up to 8 square inches sectional area, and will weld twenty to twenty-five tyres per hour. Current is supplied from a rotary converter 150 kw., 220 d.c., 150 a.c., 50 periodicity.

New Foundry (*Wheel-making, etc.*).—This is a building 160 feet long by 63 feet wide, containing two 4-ton cupolas, sand-mixing machinery, and a 28-inch pneumatic moulding machine, and various hand-moulding machines. Handling facilities are supplied by three 3-ton cranes.

New Boiler Shop.—This department is recognized as one of the finest and best equipped boiler shops in the United Kingdom. It consists of three bays, each 395 feet long, and it is 175 feet wide in the centre. The gallery is arranged for storage of plates, etc. At the south end are the riveting towers for dealing with Lancashire and other type boilers of the largest sizes. The crane equipment of this

department is very complete. There are cranes of the following capacities :—One 30 tons, one 25 tons, two 20 tons, one 10 tons, four 8 tons, and two 5 tons—all electrically controlled. The heating furnaces and gas-producers, the machine-tools, riveting and pneumatic plant, enable all leading standard types of boilers to be produced with that high degree of excellence the " Marshall " boilers have attained.

MESSRS. ROSE BROTHERS (GAINSBOROUGH), ALBION WORKS, GAINSBOROUGH.

Just over thirty years ago Mr. William Rose, the founder of this Company, invented a machine for wrapping tobacco automatically. At that time round packets of tobacco were chiefly the style of packet adopted by the tobacco trade, and when the Founder had completed his first experimental machine he was invited at the instance of Mr. H. H. Wills, of the firm of Messrs. W. D. and H. O. Wills, of Bristol, to take it there, and give it a trial run under factory conditions. The test proved highly successful, and this was the first step towards the adoption of automatic machines for wrapping up tobacco, which operation had hitherto been done by hand.

It was not long after that trial that the machines were universally adopted by all factories in the United Kingdom, and at the present time they have been installed in practically the whole of the large factories throughout the world, as not only are machines made for round packets but for square and rectangular as well.

Shortly after the Founder had manufactured this machine, he took into partnership his brother, Mr. Henry Rose, who unfortunately died a few weeks ago. Mr. Rose and his brother then devoted their attention to adopting the principle of automatic packing to other branches of industry, with the result that, at the present time, machines can be made for the packing of tobacco, cigarettes, tea, coffee, cocoa, blue, blacklead, in fact almost anything that is being put in packets, and the Firm now gives employment to between 600 and 700 hands.

A large machine shop has recently been erected in which machines of the most modern type have been installed for the production of the firm's specialities. The other shops comprise erecting shops for the various machines, pattern shops and foundries, both for the production of grey iron, brass and malleable castings.

Adjoining these works is the Company's subsidiary company, The Northern Manufacturing Company, Ltd., which specializes in all classes of machine-cut gearing for power transmission, and the equipment comprises one of the most modern gear-cutting plants in the country.

WIRE ROPES RESEARCH.

WIRE ROPES FOR USE OVER PULLEYS.

Prepared by the Reporter to the Committee, WALTER A. SCOBLE, D.Sc., of Woolwich, *Member, and issued by the Committee.*

Introduction.—During the War a considerable amount of experimental work on wire ropes was undertaken, usually to furnish information on special points. The tests were arranged to reproduce practical conditions, and decisions had to be made with a minimum of delay. There was no time for an extensive search of the literature of the subject.

Before commencing the tests for the Wire Ropes Research Committee, a considerable number of papers have been consulted and abstracted, and it is thought to be desirable to record the results in this Report, which aims at showing the present state of knowledge and opinion. With this object in view, a numbered bibliography is given, and the subject matter is subdivided under separate headings, with references by the numbers. It is somewhat difficult to prepare a bibliography. There are many papers which deal with wire ropes without reference to bending, some present no new facts, whereas others are most interesting, although they deal primarily with other subjects, and introduce wire ropes only in a secondary fashion.

The amount of reliable information obtained is disappointing when considered in relation to the number of papers written on the

subject. There is an undue amount of repetition, much prejudice, and, where conclusions depend on practical experience, they are often indefinite, usually because they neglect some of the variables involved.

There is very little experimental evidence available, and this has probably handicapped the theorists by a lack of data to work upon. Further, it is not at all clear that the subject lends itself to simple theoretical treatment.

1.—Wire.

(*a*) *Composition.*—The percentage composition for plough-steel wire rods is given by Moore (27)* as: C, 0·65–0·70; Mn, 0·35–0·50; Si, trace; P, not greater than 0·035; S, not greater than 0·035.

The Report of the Transvaal Commission (36) states that no manufacturer recommended nickel or vanadium steel.

Griffith and Bragg (72) found the composition of $3\frac{1}{4}$ inch ropes to be: Si, 0·130–0·172; P, 0·016–0·033; C, 0·58–0·90; S, 0·025–0·036; Mn, 0·23–0·58 per cent. Plough, $1\frac{1}{4}$ and $1\frac{1}{2}$ inch diameter; Si, 0·013–0·24; P, 0·021–0·053; C, 0·13–0·96; S, 0·027–0·078; Mn, 0·22–0·68 per cent.

The British Engineering Standards Association's Aircraft Specification states that the steel for high-tensile wire shall not contain more than 0·04 per cent of either phosphorus or sulphur. The percentage was raised to 0·06 during the War, and it is now proposed to allow the higher value to continue, in view of the difficulty in maintaining the lower figure, and of the lack of knowledge of the effect, on the properties of the wire, of various percentages of these impurities up to about 0·08.

(*b*) *Strength.*—Bonnaud (1) adopted an impact tensile test for the wire of ropes. He noted the number of blows of a dropping weight which were required to break the wire.

Wenderoth (2) recorded that when cast-steel wire was first

* The Nos. in brackets refer to the Nos. in the Bibliography (pages 864–867).

used, it was frequently too hard and failed by repeated bending with no sign of wear or stretch.

Rudeloff (8) foretold a point at which the brittleness of harder materials would predominate, causing a falling off of their fatigue capacity. The decrease of bending resistance with increase of tension was greater with lower tensile and more ductile wire. The resistance of strands to bending, at a tensile stress of one-tenth the ultimate strength, was greater the greater the tensile strength of the wire.

Behr (15) stated that considerably stronger material than the best, special, so-called plough-steels now used had been made and used for ropes; but manufacturers rightly do not recommend such material for winding ropes on account of its brittle nature and its liability to give way suddenly under shock. Piano wire is 25 to 50 per cent stronger than plough steel, but this result is only attained by the wire being drawn to a finer size than is advisable for winding ropes. The wires of these ropes should be stout enough to prevent corrosion and wear reducing the section too rapidly for economy in working.

On the other hand, Moore (20) records that the number of bends to failure of extra strong and plough-steel wire are equal to that for cast-steel wire. The former two are harder and so resist abrasion longer than the lower tensile wire. He also noted (27) that a 2 per cent variation of the tensile strength and number of bends gives a rope of much better service than a 5 per cent variation.

The Transvaal Commission Report (36) states that manufacturers recommend wire of from 105 to 135 short tons per square inch for the Rand. 120 is most commonly used. The lower limit is for unfavourable and the upper for favourable bending conditions. 150-ton material has given satisfactory results in particular instances.

The Review of German practice (48) showed a tendency at that time to increase the tensile strength of the wire because stronger wire wears longer, is more efficient, and costs less per ton of material raised. Iron wire was not satisfactory.

Rowland (50) says that manufacturers are agreed that the steel for winding ropes of collieries should be of as mild quality as the factor of safety will allow. On the other hand, many engineers want plough-steel wire even for shallow mines.

Baird (51) draws attention to the fact that a lower grade of wire can be drawn to a higher tensile strength. It is therefore necessary to specify both the grade of steel and the strength of the wire.

Speer (52) tested wires for ropes in tension, bending, torsion, and by bends on arcs of different radii under different tensile loads. He found that the fatigue capacity increased with tensile strength, and claimed to have disproved Rudeloff's prediction. He recommended that the material be as hard as is compatible with the pulley radius allowable.

Lloyd (53) considers that better results will be obtained with winding ropes by the use of more wires of smaller diameter, not drawn above 105 to 110 tons per square inch, than if the wire is drawn to 115 to 120 tons per square inch.

Hughes (54, Discussion) concluded that, in general, the lowest grade of wire should be used.

Baumann (55) says that Speer demonstrated the increased bending capacity of hard wires, and failed to show that they are less able to withstand shock. As their use leads to a light rope, they should be used experimentally in shallow shafts with a high factor of safety. Reauleaux's ratio of pulley to wire diameter of 550 should be altered to not less than 1,000.

Howe (69) says that the coal-mining industry uses crucible steel wire, the softest grade. Harder wire should be employed if the rope is liable to grinding, as in the handling of iron ore.

Goodman (78) points out that the strength of a wire is greater than that of the material from which it is made, and the great difference is largely due to the fact that the nominal tensile strength is much less than the real strength reckoned on the final area. Drawing wire is equivalent to producing an elongated stricture in the material, and the strength of the wire approximates to the real strength of the material.

(*c*) *Diameter.*—Newall (Catalogue) sums up the general view thus: "The bigger the pulley, the larger the diameter of the wire which can be used in the rope. Fine wires wear out quickly. Use large wires by having a large diameter pulley."

Moore (20) considered that the wire should not vary in diameter more than 0·001 inch.

Baird (51) supports Newall by recommending the use of wires as large as possible consistent with the diameters of the pulleys.

Adamson (54) concurs, and mentions that abrasion also takes place between adjacent wires.

Lloyd (53) appears to recommend the use of more wires of smaller diameter.

Hughes (54, Discussion) concluded that in general the middle flexibility should be employed, or the lowest flexibility if a ratio of pulley to rope diameter of 30 to 40 can be used.

(*d*) *Special Points.*—Newcomer (18) found the elastic limit of wire to be 80 to 90 per cent of the ultimate tensile strength, but Griffith (71) gives 65 per cent.

Bouasse and Berthier (30) discovered that wire which breaks in tension with practically no elongation, can by bending be elongated 20 or more per cent. Hard-drawn wire was wound and unwound under tension on a cylinder. Wire 1·18 mm. diameter, on a cylinder 2 cm. diameter, under 20 kg. tension, wound on eight times, elongated 24 per cent.

Speer (52) considered that the initial, internal stresses are negligible, and relieve themselves as the cable settles to its duty.

Benoit (57) noted that the twisting of the wires leaves considerable strains, especially in high-class steels.

(*e*) *Coating.*—Biggart (4) advised the use of ungalvanized steel.

Lees (9) claimed that the use of galvanized wire doubled the life of a rope, and that galvanizing did not injure the wire. Thus, for 10 *g* wire the test results were—

Plain . . .	Torsions 27.	Tension 2,215 lb.	Bends 7.
Galvanized . .	„ 25.	„ 2,178 „	„ 7.

The Transvaal Commission Report (36) states that it has been shown by Epton and Moir that by galvanizing plough-steel wire the tensile strength is not lowered, the elongation is doubled, the number of twists is reduced by 20 per cent, and the number of alternate bends is reduced 25 per cent. The resistance to corrosion by dilute acids is thirty times that of bare wire, and for partly galvanized wire the ratio is about eight times.

The Review of German Mining Practice (48) reported that bright, patent, crucible steel was almost entirely used, and that ordinary crucible galvanized wire was rarely met with.

Baird (51) supports Lees by saying that galvanizing gives 50 per cent longer life.

Speer (52) explains that galvanized wires are not so good as plain to withstand fatigue, and are not recommended, especially if of hard material.

2.—The Rope.

(*a*) *Construction.*—Aguillon (3) specified that all the wires in the same rope should be as closely alike as possible.

Biggart (4) recommended oiled, hemp cores for the strand as well as the rope.

Moore (27) considered that a mistake was often made by using seven instead of nineteen wires per strand.

Gottlob (32) argued against a strand of six wires over one. The elastic elongation of the six is greater than that of the one, so that the core wire has to carry up to 60 per cent of the whole tension.

Sunderland (63) says that the standard constructions for dredging are 6×19, 8×19, and 6×37. 6×61 is also used. The ropes always have hemp cores.

Howe (69) recommends for general hoisting, except in mines, that if the rope be over $1\frac{1}{2}$ inch diameter the construction be 6×37, and if over 2 inches, 6×61.

(*b*) *Lay.*—Aguillon (3) stated that the size of the wires and the pitch of the rope should vary with the diameters of the drums and pulleys on which the rope has to work.

The Transvaal Commission Report (36) gives the lay of the strand in the rope as from two to three times the lay of the wire in the strand, the former being most usual.

Speer (52) considered that the manner and angle of plaiting of the wires should be adjusted to the diameter of the pulley. Owing to the helical paths of the wires round the core, their changes of curvature are not uniform, and the variation is greater the smaller the pulley and the greater the angle "ω," which the helix makes with a generating line of the cylinder. If "R" be the radius at which an element of the rope lies, its change of curvature is $R/\cos^2 \omega$.

Griffith and Bragg (72) give the mean American practice as: lay of wire equals 2·75 cable diameters; lay of strand equals 7·5 cable diameters.

Roe (85) says that the life of a cable working over pulleys depends on the lays of the wire and strand.

Williams (87), asks what are the most efficient lays.

(*c*) *Lang's Lay.*—Biggart (4) found Lang's lay better than hawser lay.

Weightman (5) quoted a case of a Lang's lay rope which had done one and a half times the work of one of ordinary lay, and which was still in use.

Moore (27) considered that Lang's lay presented no advantage.

The Transvaal Commission (36) reported that all but one English manufacturer favoured Lang's lay when the cage was guided. The American engineers voted for the ordinary lay. 416 out of 427 ropes in use in the Transvaal were Lang's lay.

Baird (51) claimed that all winding ropes should be Lang's lay unless specially constructed.

Hughes (54, Discussion) in his Conclusions says, "Use Lang's lay if possible."

(*d*) *Special Ropes.*—Wenderoth (2) gave the histories of ropes used in the Dortmund and Saarbrucken districts from 1877 to 1880. The result for Dortmund was:—

Class of Rope.	Duty. Kg. metres × 10^6.	Cost per Metric Ton. Pf.
Cast-steel, flat	1,782,232	0·0115
Iron „	171,124	0·0141
Aloe fibre	1,337,250	0·00556
Cast-steel, round . . .	9,221,403	0·00567
Iron „ . . .	2,632,815	0·00509

Rudeloff (8) used a copper core for the strands. The percentage of broken winding ropes in the Breslau district dropped from 9·62 in 1882 to 1·26 in 1908, due to replacing iron by steel, and by discarding the flat form. For the same rate of working, a round rope had a 40 per cent longer life than a flat one. The maximum work done during 1908 by a round rope was 376,300 ton-kms., and by a flat, 44,500 ton-kms. The former was made of wire with a tensile strength of 120 tons per square inch.

Moore (20) refers to some ropes, e.g., 6 × 16, which are made for pliability, and also have large outside wires by combining different sizes of wire in the same rope.

King (31) asked for a Lang's lay rope which does not spin. Locked coil ropes do not spin, but they are practically solid, and so are not flexible enough for use on small pulleys. Due to its shape the wire has not a high tensile strength, usually 90 tons per square inch. He refers to Bruntons, Kilindo, which is non-spinning, and is constructed of round wire, 9 × 6 over 6 × 6 of smaller wire.

(44). In the case of cross-laid double-layer wire ropes, in which the layers are in opposite directions, the rope does not twist, but if it is twisted a few times by hand (five turns were tried here) the inner strands take the load and the outer slack off. Thus 4 tons broke a rope of over 10 tons strength. The same applies when the layers are in the same direction, because the outer layer is of greater diameter, and therefore unwinds first. If the load is under

the strength of the inner layer, twisting the rope causes the outer layer to balloon.

The Review of German experience (48) recorded that flat ropes were originally commonly used, but were disappearing rapidly in consequence of defects which are more pronounced in the flat than in the round form. The returns from the Breslau district gave :—

Flat ropes,	42·86	per cent.	lasted	less than	200	days	in constant	work.
,, ,,	57·14	,,	,,	,,	400	,,	,,	,,
Round ,,	14·3	,,	,,	,,	200	,,	,,	,,
,, ,,	17·3	,,	,,	,,	400	,,	,,	,,
,, ,,	25·5	,,	,,	,,	400–600	,,	,,	,,
,, ,,	20·3	,,	,,	,,	600–800	,,	,,	,,
,, ,,	10·8	,,	,,	,,	800–1,000	,,	,,	,,

The remainder lasted from 1,000 to 1,600 days.

Hughes (54, Discussion) recommends the avoidance of special ropes.

Griffith and Bragg (72) give as a standard, flexible rope for use on small pulleys, as in boat hoists, $6\times6\times7$, all over hemp cores. This is called a tiller rope. They also refer to the occasional use of small filling wires between the six and twelve wires of a nineteen-wire strand.

Williams (87) asks for data concerning the bending of 6×7 cable, because this construction is almost invariably used for the hauling ropes of aerial ropeways.

(*e*) *Cores.*—The Transvaal Commission (36) reported that steel cores of circular wire are better than hemp. The latter loses its shape under heavy pressure, as when wound in more than one layer on a drum. Then water enters where the strand has opened. Epton favours high tensile wire cores, although lower tensile wire is commonly used.

Griffith and Bragg (72) recommend manila as the fibre for cores, on account of its tensile strength, and because it stands moisture and alternate bending, and resists sea-water.

(*f*) *Corrosion.*—Lees (9) wrote that with winding ropes in wet

shafts, exposed to steam or furnace gases, corrosion takes place at (1) the cap end; (2) where the rope rests on the pulleys when the cages are at the top and bottom of the pit; (3) the underlapping rope on the drum. At (2) and (3) the rope is opened by the bending and moisture enters. The hemp core retains moisture, but a wire core is but little better.

Thornton Murray (46) pointed out that the outside of the cable is often cleaned by passing over the pulleys, whereas it is corroded internally. He believed that repeated bending assists corrosion.

Speer (52) found that the amount of rusting was greater with harder wires, and Howe (69) confirms that the rusting is greater with a higher grade of steel.

(*g*) *Lubrication.*—Wenderoth (2) emphasized the need of a lubricant which should not harden.

Biggart (4) and Adamson (54) showed that an oiled rope has from two to three times the life of a dry rope when working over pulleys, especially if it is working within the elastic limit of the wire.

Howe (34) says that linseed oil should be used.

The Transvaal Commission (36) recommended that a rope should be lubricated during its manufacture. Stockholm tar, tallow, and resin are unsuitable as lubricants because they are acid.

Chapman (47) showed experimentally that lubrication decreases the internal friction of a rope.

Rowland (49) says that greasing a cable not only protects the outside from corrosion, but also lubricates the inner surfaces and preserves the hemp core, which, if it becomes dry, will crumble away with disastrous results. The chief use of the lubricant is to lessen the friction of the internal wires, which chafe heavily on one another when a loaded rope passes over a pulley. Therefore the compound should be worked well into the interstices. Constant friction between the wires causes wear and is believed to induce fatigue. Lubrication increases the number of bends of a rope from 16,000 to 38,700 (Biggart) before breaking. Linseed oil is not good because it dries and peels off, or else hardens and prevents the

next oil applied from reaching the inside of the rope. It also tends to harden the core and hasten its destruction.

The *American Machinist*, 21st February 1914, states that steel wire hoisting ropes are lubricated with boiled linseed oil. Haulage ropes require greater substance, for example, pine tar with one-tenth raw oil, boiled at a low heat and applied warm. Care must be taken not to burn the tar.

(*h*) *Modulus of Elasticity.*—Leupold (15, Discussion) quotes Hrabák to the effect that the equivalent modulus of elasticity of a 6×19 cable, E′, is $0\cdot44$ E, E being that of the wire. There is a rapid increase of E during the first few weeks' use of a new rope, and then a more and more gradual increase until apparently a maximum is reached. E′ should be taken as $0\cdot72$ E to calculate the bending stress.

Howe (24) gives the following values of E′ to be used for calculating the bending stress in the wire of a rope bent over a pulley.

Construction .	6×7	6×19	6×37	8×19
E′ . . .	$1\cdot37\times10^7$	$1\cdot20\times10^7$	$1\cdot13\times10^7$	$1\cdot10\times10^7$

Guidi (41) found the modulus of elasticity of ropes to vary from $10\cdot5\times10^6$ to 29×10^6 lb. per square inch.

Panetti (42) gives a theoretical analysis to estimate the E of a cable, and appears to be alone in taking account of the effect of lateral contraction.

Speer (52) noticed that E is greater for a harder material.

Howe (69) develops a method for calculating the E′ of any strand or rope, and gives the following test results for comparison :—

Number of wires in strand .	7	19	37	61
Angle of outer wires . .	9° 54′	15° 30′	16° 33′	17° 8′
E′ of strand . . .	20×10^6	18×10^6	$16\cdot7\times10^6$	17×10^6

Construction of rope	6×7	6×19	8×19	6×37	6×42
Angle of strands .	14° 40′	17° 52′	20° 44′	17° 52′	19° 15′
E′ of rope . .	$12\cdot8\times10^6$	$11\cdot4\times10^6$	10×10^6	$10\cdot4\times10^6$	7×10^6

Griffith (71) tested various 6×19 ropes and found E′ to vary from $6 \cdot 3 \times 10^6$ to $8 \cdot 9 \times 10^6$.

(*i*) *When a Rope should be Scrapped.*—Diescher (6) found the ultimate strengths of old ropes to be remarkably high, due to the fact that the breaks of the wire are scattered. A rope should be thrown out when 40 per cent of the wires are broken in the length of the pitch of the strand.

Hrabák wrote that, when the modulus of elasticity of a rope appears to diminish, the rope is giving way and is unsafe. He recommended tests of E′ at intervals as a good means of inspection.

Epton (37) also noticed that the actual strength of worn ropes is in most cases greater than that of the separate wires at their most worn parts. The wires are held in and laterally supported by the other wires.

McCann and Colson (39) determine the changes of sectional area of a rope by the alteration of its self-induction. They use a solenoid over the rope.

Adamson (54) states that the first wire breaks at about half the life of the rope.

Baumann (55) comments on the fact that Speer admits that if a wire breaks it takes up its load again at the next turn of the spiral. The regulations compel a rope to be rejected when the number of breaks equals the number of the strands in the rope, regardless of the length. He suggests that wasteful rejections can be avoided by assuming that the number of ineffective wires are those fractured in the worst two pitches, or in a length of one metre.

Wahn (68) also discusses the maximum permissible number of broken wires in a rope. He has an apparatus to determine the number and also to which wire in the strand each fracture belongs.

3.—Pulleys and Drums.

(*a*) *Diameter.*—Aguillon (3) gave the minimum pulley diameter as 2,000 wire diameters. The relation to the size of the rope matters less, because the disadvantage of too small a drum can be

obviated by selecting a suitable size of wire and by the construction of the rope. However, the smallest pulley should not be less than 48 rope diameters.

Biggart (4) considered that taking the pulley diameter as six rope circumferences, irrespective of the wire diameter, is wrong. The size of the component wires must be considered. He also wrote that the user will be content to pay for a greater number of ropes, rather than have pulleys made of such a diameter as theory and practice point out to be necessary for a long life; and in so doing he will be the gainer, as in almost all cases increased economy is obtained through the use of comparatively small pulleys.

Diescher (19) considered that the diameter of sheave should be not less than 48 rope diameters.

Howe (34) tabulates sizes for crucible and plough-steel ropes, which are summarized here:—

6×19 rope, hemp core, minimum sheave diameter, 48 rope diameters.

8×19	1½ inch	30	
	¼	36	
6×61	3¼	40	
	2	36	
6×37		31 to 32	

Chapman (40) again pointed out that the ratio of pulley to rope diameter is usually given without reference to the construction.

Baird (51) requires that the diameter of the drum and pulleys must not be less than 100 rope diameters or 1,000d, where "d" is the diameter of the largest wire in the rope.

Adamson (54) attempted to make clear the importance of the pulley diameter, by writing that the life of a cable is doubled by an increase of pulley diameter equal to two rope circumferences.

Hughes (54, Discussion) considered that the pulley diameter should not be less than 26 rope diameters.

Blasius (62) shows that the pulley diameter is a minimum if the diameter of the wire is adjusted so that the bending is twice the tensile stress. (As this result is obtained by taking the

number of wires constant, it is not clear that it is of any practical value).

Howe (69) advises the use of a standard construction if possible.

For ropes of the same diameter	6×7	6×19	8×19	6×37	6×61
Wire diameter is represented by	100	60	50	43	33

The sheave diameters should be proportioned to these numbers.

Use 20-30 rope diameters: for derricks, 6×19 and 8×19.
„ 40 „ „ „ coal towers, 6×19.
„ 30 „ „ „ ladle cranes in steel mills, 6×37.
„ 60-100 „ „ „ mine hoists, 6×19.
„ 50-80 „ „ „ lift bridges, 6×19.

Griffith (71) tested the loss of strength of a rope broken over a pulley, and gives

23 per cent loss on a pulley of 8 rope diameters.
13 „ „ „ 15 „ „
4 „ „ „ 30 „ „

Ketchum (79) for 6×19 hoisting rope on hemp core, gives tables of the minimum pulley diameter and rope diameter. The ratios are, for cast-steel—

43·6 for a rope $2\frac{3}{4}$ inches diameter.
36·0 „ „ $\frac{1}{2}$ „ „
24·0 „ „ $\frac{1}{4}$ „ „

and for plough-steel—

61 for a rope of 2 inches diameter.
48 for ropes of $\frac{1}{2}$ and $\frac{1}{4}$ „ „

Bottcher and Tolhausen (Cranes), recommend the use of 6 × 19 rope on large drums, with a minimum sheave diameter 25 times that of the rope. The minimum diameter of small drums should be 20 times that of the 6 × 37 rope used thereon.

Richards (22) specifies a sheave diameter of 115 rope diameters for a 19-wire, and 185 for a 7-wire strand.

(*b*) *Condition of Pulleys*:—Achard (Proc. I.Mech.E., Jan. 1881) recommended that the grooves of pulleys should be lined with leather set on end. Wood pulleys also increase the life of a rope.

Aguillon (3) specified a wood lining for pulley grooves.

Diescher (6) remarked that for heavy ropes, under high tension, lining the grooves was not worth while, because the lining was worn out too soon.

Newcomer (18) drew attention to another point, that new ropes, replacing old ones which had worn into the sheave, last a shorter time.

Diescher (19) considered that the groove should fit the rope on a third of its circumference. Where the rope deflects from the direction of the groove, the radius at the bottom of the groove should be greater than that of the rope. The inner faces of the groove flanges should also be flared in order to clear the rope.

Moore (27) called for a lining to the grooves of Russian hemp or other fibre. It is not good practice to run wire ropes in iron grooves.

Howe (34) wrote that cast-iron pulleys and sheaves should be lined with blocks of hardwood set on end, which can be renewed when worn out. This saves wear of the rope and increases the adhesion. For a high speed use leather on end, or rubber.

Baird (51) regarded wood-clad drums as better than iron or steel.

Benoit and Woerle (57) found that a rope lasted better on a pulley of good finish.

Wahrenberger (65) says that the life of a cable depends on the influence of the drum and pulleys on the tension on the cable, and on the pressure resulting from the friction between the running pulley and the cable. Failure is often caused not so much by bending, *per se*, as by the higher specific pressure between the cable and the pulley which are in contact at relatively few points. This pressure is reduced by the adoption of grooves to fit the cable, and by the cable having as much surface as possible in contact with the wheel.

(*c*) *Slip on Pulleys.*—Baird (51) points out that there should be no slip of the pulleys.

Williams (87) asks if there is any slip between an endless rope and the sheaves.

4.—The Repeated Bending of Wire Ropes over Pulleys.

(*a*) *General.*—Biggart (4) found that the outside wear of a rope was only appreciable on large pulleys which allowed a large number of bends.

Thurston (15, Discussion) remarked that the inside wires are worn where they touch adjacent wires.

Diescher (19) pointed out that there is torsion of a rope where deflection occurs.

Moore (27) considered that more mistakes were made by buying ropes too large than too small for the service.

The Transvaal Commission (36) reported that inferior wire for ropes, although it stands tension, torsion, and bending, has its inferiority disclosed under these stresses when rapidly repeated.

Chapman (47) considers that, in bending, two qualities are met with, the flexibility and internal friction. If a rope be bent through a complete cycle within the elastic limit, reversing the direction, the force-deflection diagram is like a hysteresis loop. Its area is a measure of the internal friction, and the inclination of the centre line is a measure of the flexibility.

Speer (52) found that the fatigue capacity increases with diminution of load much more slowly than with an increase of pulley radius.

Unwin (73) concludes that the destruction of a rope is due to (1) wear of the outer surface; (2) wear due to the rubbing and pressure of the wires on each other; (3) fatigue of the steel due to repeated bending over the pulleys.

(*b*) *Theory of the Bending Stress in the Wire.*—Leupold (15,

Discussion) quotes Hrabák to the effect that $E' = 0{\cdot}72\,E$ should be taken for an ordinary used rope when calculating the bending stress.

Austin (15, Discussion) gave a formula which he attributed to Wm. Hewitt, Vice-President of the Trenton Iron Co.

$$\text{Bending load} = \frac{Ea}{2{\cdot}06\ R/d + c}$$

$E = 28{,}500{,}000$. a is the total section of the rope. d diameter of the wire. R radius of pulley. c is a constant which depends on the number of wires per strand.

For a 7 wire strand, $d = \frac{1}{3}$th rope diameter, $c = 27{\cdot}54$
„ 19 „ $d = \frac{1}{15}$th „ $c = 45{\cdot}9$

The largest outside wire diameter must be taken if the wires vary in size.

Values were calculated from the formula and given in a Table which is included in an abbreviated form here.

19 *Wire Strands: Stress due to Bending.*

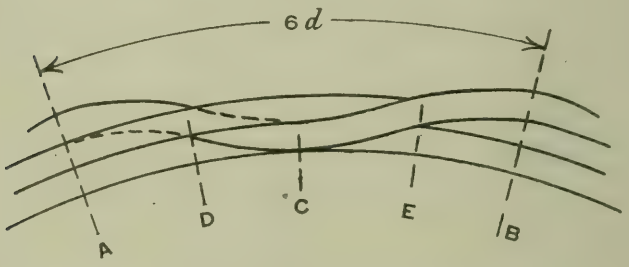
Rope Diameter.	Pulley Diameter.									
	6″	8″	10″	12″	18″	24″	36″	72″	96″	120″
¼ inch	1,801	1,390	1,131	965	654	495	338	167	126	101
⅜ „	—	3,776	3,094	2,620	1,796	1,366	924	469	353	283
½ „	—	—	—	6,609	4,573	3,495	2,376	1,212	913	733
¾ „	—	—	—	—	15,309	11,807	8,101	4,173	3,153	2,534
1 „	—	—	—	—	—	27,612	19,113	9,937	7,528	6,059
1½ „	—	—	—	—	—	—	61,238	32,403	24,662	19,906
2 „	—	—	—	—	—	—	—	74,795	57,183	46,285
2½ „	—	—	—	—	—	—	—	145,246	111,546	90,540

The description, stress due to bending, is applied here to the

maximum bending stress in the wire. This is multiplied by the area of the rope and added to the load to give the effective tension from which the factor of safety may be calculated.

Diescher (28) advanced a theory which is essentially different from that discussed by others. He remarked that abrupt bends cause a lateral spreading of the strands and a flattening of the rope. It takes more effort to bend a rope if taut than when it is slack. Wires bound at one end bend simply and require a moment equal to the sum of the moments for the single wires. Wires bound at each end buckle on the concave side and offer a much greater resistance. Fig. 1 represents a rope on a sheave. By the bending

Fig. 1.



C is pressed on the sheave. The arc DCE flattens and the space DE spreads. Since D and E are not fixed, and AD and EB are in tension, and, further, through the bending of the rope the chords AD and EB must expand as much as the chords DC and EC must contract, therefore the compression cannot manifest itself, because the pressure at C must forward the local surplus towards A and B. The increment which the upper fibres lack is drawn from the concave side of the rope, whence an equal increment is displaced. Taking a coefficient of friction, 0·15, the total pressure of the rope on the sheave is $2\pi T$ per turn. Taking a 2-inch rope on an 8-foot pulley, under a tension of 30,000 lb., the pressure is 7,200 lb. per foot. The pitch is 12 inches. The resistance opposing compensation amongst the strands is, $7{,}200 \times 0{\cdot}15 = 1{,}080$ lb. $= 6{,}480$ lb. for six strands, which is the bending stress in the rope.

The power consumed in bending is the product of the bending

stress and the motion in the strands in the process of adjustment, which in one revolution is 2π inches or 0·5 foot, approximately. Therefore the work of bending is $0{\cdot}5 \times 6{,}480 = 3{,}240$ foot–lb.

If the diameter of the sheave be halved, the pressure is doubled the compensating motion in a given length of the rope is doubled, and the energy consumed is quadrupled, that is, for the same rope velocity, the resistance opposing the adjustment of the strands is proportional to $1/D^2$.

The discussion brought out the fact that the coefficient of friction of strand on strand should have been taken instead of rope on pulley, and that the wear and tear of rim, and the power required to turn the pulley, are also proportional to $1/D^2$. Multiplying by the number of strands was queried. It indicates that 8 strands are less flexible than 6.

Howe (34) gave the stress due to bending as $0{\cdot}45\ Ed/D$, where d is the diameter of a component wire. D is the diameter of the pulley. He now (69) takes the modulus of elasticity of the rope instead of $0{\cdot}45E$.

Chapman (40) estimates the bending stress as $Ed \cos^2 \alpha \cos^2 \beta/D$.

α is the angular pitch of the wires in the strand.

β „ „ „ strands in the rope.

In direct tension each helix of wire is not perfectly free to behave as a spiral spring in tension, hence, although the elongation of the rope as a whole is greater than it would be if it consisted of a bundle of wires, it is less than for a number of free helices. Doubtless in some degree the same action occurs in a rope bent over a pulley.

Benoit (56) considers that tests show that the Reauleaux formula should not be amended by a factor less than unity. The stresses are really greater than those given by that formula.

Leffler (58) adopts the Chapman formula, and takes the extreme fibre stress in an individual wire

$$K = \frac{Ed \cos^2 \alpha \cos^2 \beta}{D}$$

total allowable tension in rope,

$$P = a\left(S - \frac{Ed \cos^2 \alpha \cos^2 \beta}{D}\right)$$
$$= a\left(S - \frac{1{,}800{,}000\, c}{D}\right)$$

since $d = c/15$ for 19 wire strand.

d is the diameter of the thickest wire.
a is the sectional area of the rope.
S is the maximum working tension.
c is the diameter of the rope.

Hardisty (70) regards a wire rope as consisting of helical springs. If the lubrication is good they slide over each other when the rope is bent, and a strand which is in tension on the outside of a bend is in compression on the inside of a bend at a short distance away. This tends to equalize the stresses in the strands, and the flexibility is greatly increased over that of a rope composed of straight wires. The stress due to bending is $E\frac{d}{D} \cos \alpha \cos \beta$, which he claims is in agreement with the mean slope of Chapman's hysteresis loop.

Rankine (77) gave the stress due to bending, S = 1,894,000 c/D, where c is the rope diameter.

Ketchum (79) apparently follows E. T. Sederholm of the Allis-Chalmers Co, and converts the Rankine bending stress into a bending tension in the rope, by taking the product of the maximum bending stress and the sectional area, which gives $750{,}000c^3/D$. The values are calculated for each rope on pulleys of different diameters, and are then deducted from the working strength of the rope. The remainder is plotted against the pulley diameter as the safe working load, and a separate curve is obtained for each rope.

Williams (87) believes that the calculation of the bending stress from $\frac{3}{8} E\, d/D$ leads to a high result. He appears to be thinking somewhat on the same lines as Mallock (64), when he inquires if the stress in the wire can be expressed in terms of the number of bends which the rope will stand. He asks whether, for the same rope diameter, the bending stress is proportional to the diameter of the wire; and also, whether an increase of rope tension

increases the bending stress by making the rope stiffer through preventing the wires and strands from moving on each other. He draws attention to the fact that as the rope passes over a pulley the bending stress varies 0—max.—0, and so has double the effect of a constant stress of the same magnitude.

Vaughan (88) writes that the stresses due to bending must be less than Ed/D, or a wire of 0·07 inch diameter on an 8-inch sheave would break.

(*c*) *Double or Reverse turns.*—Biggart (4), and Adamson (54), found by experiment that reverse bending halves the life of a rope.

Hughes (54, Discussion) remarked that there was hardly any limit to the pulley diameter required if reverse bends were employed.

Howe (69) agrees that a reverse bend is much more severe on the rope than a direct bend.

(*d*) *The Angle of Bending.*—Aiguillon (3) advised the use of a larger head pulley with a greater angle of lap.

Mines and Minerals (17) gives the opinions of different American manufacturers in regard to the effects upon the rope of the length of the arc of contact on the sheave. They were asked to compare a lap of 180 degrees with 45 degrees or less, on a sheave of the proper diameter.

J. A. Roeblings' Sons Co.:—

There is very little difference, assuming that no part of the load is held by adhesion between the rope and sheave.

Hazard Manuf. Co.:—

Forty-five degrees is less destructive than 180.

American Steel and Wire Co.:—

The curvature in wire rope extends its displacement beyond the actual tangent points of contact and bearing. If the length of the arc of contact exceeds the length of the no-contact displacement, that portion of the rope has received its maximum displacement, and any increase of the arc of contact would effect no further deterioration of the rope. This considers curvature alone. When the pressure is sufficient to flatten the rope materially, it becomes a

very potent factor. For 45 degrees the pressure per inch is 72 per cent of that for 180 degrees of contact, so the rope has less tendency to deteriorate.

Trenton Iron Co.:—

In most cases for arcs of contact of 45 to 180 degrees the rope is bent to the curvature of the sheave, and there is no difference of bending stress. For slight bends,

$$R = \frac{E d^1 u}{5 \cdot 25\, t \cos \theta/2}$$

R is the radius of curvature in inches.
d is the diameter of the wire.
u is the number of wires in the rope.
t is the load in lb.
θ is the angle of the bend.

A Table is prepared which gives the theoretical radius of curvature for one pound tension, and to determine the actual radius of curvature, where this exceeds the radius of the sheave, the tabulated radius is divided by the actual tension.

Leffler (58) remarks that if a rope is in contact with a sheave over a small arc, the actual radius of curvature may be greater than that of the sheave.

$$R = \frac{4\, d^2}{17 \cos \theta/2} \sqrt{\frac{E}{W}}.$$

R is the actual radius of curvature.
θ is the angle between the directions of the rope.
W is the pull on the individual wires.

If R be greater than the radius of the sheave, 2R should be used instead of D. The formula is only valid from 130 to 180 degrees.

Wahrenberger (65) considers that the life depends on the arc of contact, and that a small arc is prejudicial.

Howe (69) says that a 90 degree bend is as bad as 180 degrees on the same diameter sheave.

Vaughan (88) tested wire only, and found that in hand-bending tests on pulleys, if the bend is not carried through 180 degrees, the number of bends is largely increased.

(*e*) *Other Considerations.*—Behr (15) wrote that the counterflexure of the rope, due to the two diverting sheaves at the junction of the two stages, need not cause too rapid deterioration, if the sheaves be made large and be placed at some distance apart, so that the reverse bending does not succeed the first bending too rapidly.

Laschinger (15, Discussion) remarked that the more suddenly a rope is bent, the higher is the initial bending stress in the wires.

Diescher (19) pointed out that there is torsion where deflection occurs.

Moore (20) records that all authorities seem to agree that the deterioration increases proportionately with greater speed and load.

Leffler (58) advises that if the stresses be reversed at the rate of ten or more times per minute, the working stress should be halved.

Wahrenberger (65) believes that the life of the rope depends on the distance between the pulleys, and from the pulley to the drum.

Smith (67) says that at the commencement of every wind upwards there begins a rotating movement in the rope as it passes over the head gear pulley. The end of the cage being fixed, the effect of this, as the cage approaches the top of the shaft, is that a tightening, twisting movement is accumulating in the rope, which causes excessive compression on the centre core. On a section of the rope which has passed the head-gear pulley, the rope strands have a corresponding tendency to unlay.

Williams (87) asks the effect of the rapidity of bending.

(*f*) *Test Results.*—The test results given by Biggart (4), and studied by Adamson (54), have proved extremely valuable. These are readily accessible and cannot be included in detail here. Plotting the results did not show where the working stresses passed through the elastic limit. Wires tested singly had a better life than when in a rope. Single wires often failed at working stresses well within the elastic limit of the material.

Hughes (54, Discussion) gives full records of the performance of thirty-two ropes used on lifting appliances on the Lancashire and Yorkshire Railway. His conclusions are included under the appropriate headings.

Rudeloff (8) experimented with wires and strands under tension and bending. The wire was 2 mm. diameter and had tensile strengths of 24, 32, 51 and 76 tons per square inch. The resistance to repeated bending diminished rapidly as the tensile stress in the wire was increased up to 2 tons per square inch, and then more slowly for higher tensions. The resistance to repeated bending of a single wire was found to be much less than that of a strand made from the same wire.

Benoit and Woerle (57) used 1 mm. wire of 110 to 114 tons per square inch tensile strength. Tests were made of the wire singly, as a strand of six wires over a softer core of 55 tons per square inch, of three of these strands formed into a rope, and of five strands formed into a rope on a hemp core. In these preliminary tests the specimens were bent and unbent in one direction under a stress of 5 tons per square inch.

On a pulley 175·4 mm. diameter,

A single wire stood 198,170 bends.
A strand stood, until one wire was broken, 44,800 and 47,190 bends.

On a pulley 180·4 mm. diameter,

A single wire stood 122,000–200,000 bends.
A strand stood 40,860 bends (3 wires broken).

A three-strand cable stood	22,860 bends	(1 wire broken).
	36,440 ,,	(completely broken).
A five ,, ,, ,,	35,000 ,,	(failure commenced).
	40,000 ,,	(test stopped).

After annealing,

A single wire stood	47,700 bends.	
A strand ,,	37,000-42,000 bends	(complete destruction).
A three-strand cable stood	21,850 ,,	(,, ,,)

Simmons (64) from tests of 10 and 20 cwt. aircraft flexible cable, high tensile, on 1 to 4 inch diameter pulleys, found that the number of bends to failure could be expressed as $\frac{kD^{\frac{5}{2}}}{T}$. k is a constant. D is the pulley diameter. T is the tension on the cable.

n is 1 for the 20-cwt. cable under tensions from 200 to 400 lb.; it is 2 for the 10 cwt.-cable under tensions from 100 to 200 lb.

Mallock (64), suggested that a comparison should be made of the work done in bending the cable over a pulley, with the fatigue produced by repeated bending. By investigating this, Simmons found that the work done to fracture the cable was constant on pulleys of different diameters and under various tensions. The work done to fracture was taken as the product of the force required to move the cable on the pulley, and the total distance moved until fracture. Simmons refers to the product of this force and the radius of the pulley as the permanent set bending moment.

Mr. Major's Memorandum (86) records the performance of ropes in service. Four ropes were employed in each case, two each of different types, each rope being coupled to one of the competing type through a rocking beam with equal arms, which ensured an equal distribution of load between the ropes of each pair. All the ropes of a set worked over the same wheels.

(1) Passenger lift constantly at work.

Load, 7 cwt. Cage weight, 9 cwt. Travel 90 feet 7 inches at 165 feet per minute.

Two ropes were of 75,000–80,000 lb. per square inch wire, Lang's lay $1\frac{3}{8}$ inch circumference; $6 \times (1 + 6 + 9)$ on fibre core. Two ropes were of the same wire but 6×9 on fibre with fibre core.

The rope passing over the V-wheel did not reach the head wheel.

Head wheel, 36 inches diameter; 180 degrees lap; U-groove $\frac{1}{16}$ inch greater radius than the rope.

V-wheel, 27 inches diameter, 180 degrees lap, V-groove of 35 degrees. Head wheels to balance weight, 27 inches diameter, grooved as cage wheel, 90 degrees lap. The rope passes over two wheels but no other.

After four years the outer sheathing of the Lang's lay rope showed broken wires, and it was removed. The other rope was flattened at the crown, but the wires had not broken; it took a pear section at the V-pulley. It was still working after 6 years 5 months and appeared to be good for a further life of 6 months.

(2) Passenger lift constantly at work.

Load, 7½ cwt. Cage, 9 cwt. Travel 74 feet at 150 feet per minute.

Ropes as for 1, but soft iron central wire in strands of Lang's lay rope. Wheels as in 1, but only one pulley to the balance weight.

No part of a rope passed more than one wheel.

All wheels 24 inches diameter and lapped 180 degrees.

After four years the outer wires were broken, but not so badly as in 1. This was probably due to the use of only one head wheel. The load was greater and the wheels were smaller. The wires were flattened in the other rope and a few were broken.

All four ropes were worn out after 6 years 4 months. The compound strand rope was more damaged than that with the single layer, but tensile tests of the most worn portions showed the former to be the stronger. The compound rope is clearly the better.

(3) All compound ropes as before, with hard steel central wire for one pair and soft iron for the other.

Load, 9 cwt. Cage, 9 cwt. Travel 90 feet at 200 feet per minute.

V-wheel, 30 inches diameter, 180 degrees lap. Overhead wheel 36 inches diameter, 180 degrees lap. Two wheels to balance weight, 30 inches diameter, 90 degrees lap.

After 4 years 1 month, all ropes were equally worn with no broken wires. After 6 years 1 month, there were very few broken wires and the ropes still had a long life. The result was better than 1 and 2, although the load was heavier, due to the use of larger wheels.

(4) Passenger and goods lift making 200 trips per day.

Load, 10 cwt. Cage, 14 cwt. Travel 65 feet at 150 feet per minute.

Four feet of the rope ran over the V-wheel and one head wheel.

V-wheel, 24 inches diameter, 180 degrees lap. Overhead wheel, 45 inches diameter, U-groove, 180 degrees lap. Pulley to balance weight, 22 inches diameter, 180 degrees lap.

Ropes ½-inch diameter, 6 × 16 on fibre core, and Lang's lay.

After two years there were a few broken wires at the 22-inch wheel only.
„ $2\frac{2}{3}$ „ , at 45-inch wheel, no broken wires, at 24-inch V-wheel one per cent were broken, at 22-inch wheel, 10 per cent.
„ $3\frac{1}{2}$ „ , new ropes were required.

Mr. Major's conclusions are to the effect that, for wheels of the same diameter, a V-groove of 35 degrees, with its double tread, has less wearing effect than a single tread. The diameter of the wheel is more important than the form of the groove. No portion of a rope should pass over more than one wheel if it can be avoided.

Vaughan (88) from the repeated bending of wires of from 0·03 to 0·14 inch diameter on the Vaughan-Epton machine, gives for small wires, under moderate tension, on a large sheave, $N = \frac{0{\cdot}05D^2}{d^3}$ which probably holds when the sum of the tensile and bending stresses is within the fatigue limit. If the ratio of pulley to wire diameter be less than 150, the number of bends is less and the power of d reduces gradually from 3 to 2. $N = \frac{0{\cdot}44D^2}{d^2}$ when $D = \frac{1}{2}$ inch.

Increasing the factor of safety in tension beyond a certain limit does not further increase the life.

Conclusion.

The makers of wire ropes frequently specify a factor of safety which depends on the use to which a wire rope is put, and the minimum pulley diameter for each rope. This provides no exact information for the case considered, and none at all if the cable be used on a pulley of different diameter. Other writers, notably American, attempt to place the subject on a better footing by calculating the bending stress and adding it to the tensile stress produced by the load.

It appears that a general method cannot be applied to the design of ropes, as at present made, for use over pulleys. Not only are there insufficient data; entirely different problems present themselves. Thus the outside wear is most important for a rope working on a large pulley, whereas bending fatigue and internal

wear do most damage when a small sheave is used. It is possible that generalization, sometimes unintentional, but caused by the conditions not being clearly stated, has led to some confusion.

The calculation of the bending stress for design does not at present appear to be satisfactory. In the first place there is a lack of agreement on the factor to be used with the Reauleaux formula. There is no rational formula which covers the actual conditions, and the bending stress has not yet been shown to be the determining factor in the destruction of a rope.

It is suggested that an attempt should be made at an analysis which will separate the three destructive effects, namely, *outside wear*, *wear between the wires*, and *bending fatigue*. Their relative importance must depend primarily on the diameter of the pulley, but there are other variables to be considered.

The various points which are brought forward by the abstracts are now briefly reviewed.

The chemical composition of the steel-wire rods seems to be left to the maker and the wire-drawer. Considerable variation is met with in American practice.

No distinction is drawn between hardness and tensile strength. They are generally regarded as increasing together. Up to a point it is agreed that wire of higher tensile strength gives a better performance, even over pulleys. Above this point the manufacturers are not inclined to go, and they are supported by some engineers. There is a fear of brittleness and loss of shock resistance. On the other hand, there seem to be no published data to support this view, whereas several experimenters enter a plea for higher tensile wire, and there is a demand for it from many users for certain purposes.

Very little attention has been paid in published matter to the desirability of uniformity of the wire in all respects.

The information concerning the wire diameter indicates a difference of opinion which was not expected. There is the compromise by the use of outside wires of larger diameter.

The question of coating affords a fertile subject for discussion.

Some writers have asked for an adjustment of the lays to suit

the diameter of the pulley, but there is no exact information which bears on this point.

The balance of opinion favours Lang's lay where it can be used, but the preference is not shown so clearly by American engineers.

Nor is there agreement as to the best type of core, although one of fibre is generally advised.

The necessity of a lubricant is universally recognized, as is the fact that it should not be acid, but the best to use under any given set of conditions is not so clear.

Further information which would lead to a closer estimate of when a rope is unsafe, and therefore should be removed, would be very valuable.

The ratio of the pulley to the rope or wire diameter varies considerably for different uses. The adjustment of the mode of construction to this ratio needs further investigation, as does the performance of ropes on pulleys of different diameters.

The condition and the lining of pulleys, and the form of the groove, have been the subjects for remarks, but there are few quantitative data.

The effect of different angles of bending of a cable over a pulley appears to be explained very clearly by Leffler, although other opinions are at variance with his conclusion. But the formula he gives to calculate the true radius of curvature of the rope does not agree with that of the Trenton Iron Co.

There are few, if any, data available concerning the matters which are collected under "Other Considerations."

The volume of test results is unfortunately small. The reduction of strength in bending by stranding the wires is worthy of further inquiry, as is Mr. Mallock's suggestion, which might lead to the performance of a rope being predicted from the result of a simple experiment, and so avoid the necessity of a large number of long fatigue tests to fracture.

Mr. Major's contribution again brings out the fact, which must be well known to those who have experimented with wire or rope, that false conclusions are likely to be drawn from insufficient data. Wire and ropes vary appreciably from point to point, and from

rope to rope even when made to the same specification. The first comparison indicates that the fibre-core rope was better than the Lang's lay with solid cores for the strands. The second set makes it appear that the adoption of a soft-wire core improved the Lang's lay rope, but this is not confirmed by the third set of results.

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84. Pulleys for Wire Ropes. W. E. Hogg.
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86. Memorandum on Rope Life. C. G. Major.
87. Communication from A. E. Williams.
88. Memorandum No. 1 of Experiments with the Vaughan-Epton Fatigue Testing Machine.

[*For list of the Wire Ropes Research Committee, see next page.*

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HELICAL SPRINGS.

By W. NORMAN THOMAS, M.Sc., of the University of Birmingham,
Associate Member.

[*Selected for Publication.*]

It has been observed that, in practice, many springs fail under smaller loads than those for which the springs were originally designed, and it is to account for these unexpected failures that the following analysis of the stresses in helical springs of round wire, is put forward.

The investigation shows that there are two considerations which may easily be overlooked in the design or use of a spring :—

(i) The effect of eccentricity of the load.

(ii) The effect of the direct shear stress, as distinct from the torsional shear stress, in the material of the spring.

(i) Unless the spring is carefully designed—particularly a compression spring—there may easily be an appreciable eccentricity of the loading; the effect of such eccentricity is clearly shown in the notes below.

Whether the maximum principal stress or the maximum shear stress in the material is taken as the criterion of failure, there is a considerable diminution in the factor of safety when the load is not axially applied—probably in many cases the factor is reduced to unity, and failure occurs.

(ii) The effect of the direct shearing force is not so important, and it is usually neglected in spring calculations. It will be seen, however, in what follows, that it may be of sufficient importance

to warrant consideration. It is not suggested that unexpected failures are due entirely to overlooking these two points. Often data concerning the loading are so very difficult to estimate that, quite possibly, in many cases failure is simply due to under-estimation of the magnitude of the applied loads and of the effects of impact and "repetition" of stress. In a considerable number of cases, too, failure may be due to the fact that the springs were designed for normal temperature work and then afterwards employed under very high or very low temperature conditions.

Close-Coiled Springs.—Let the mean radius of the spring be R, and the diameter of the wire d.

Let the load W be applied at B, Fig. 1, at a distance mR from

Fig. 1.

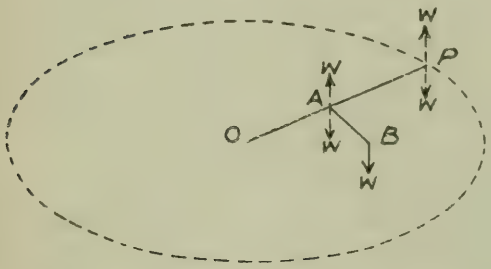
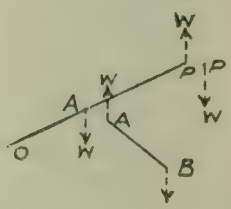


Fig. 2.



the centre O of the coils. The effect of the load upon the wire at a point P, where OP makes an angle θ with OB, may be analysed as follows:—

Let AB be perpendicular to OP at A, and imagine one pair of equal and opposite vertical forces W at A, and a similar pair at P. Then as each pair is in equilibrium, the condition of the spring is unaltered, but the effect of the single load at B on the section at P may be better understood by considering it replaced by

(i) a couple W. AB
(ii) „ „ W. AP
(iii) a single force W at P

(*see* Fig. 2, where these components are separated).

Fig. 3.—*Showing Bending Moment in various parts of the Spring for different Eccentricities of the Load.*

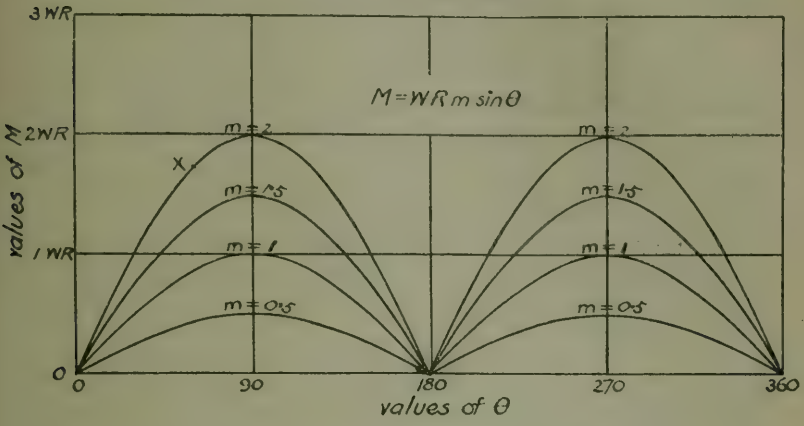
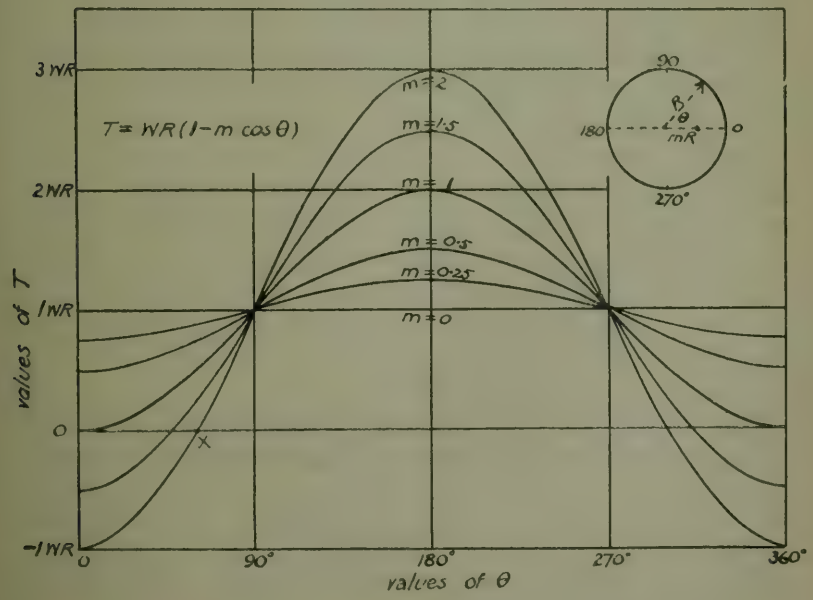


Fig. 4.—*Showing Twisting Moment in various parts of the Spring for different Eccentricities of the Load.*



The couple W. AB produces a bending moment M on the wire at P and acts in a vertical plane.

$$M = W.\ AB = W\ mR \sin\theta \quad . \quad . \quad (1)$$

The couple W. AP produces a twisting moment T on the wire at P, as AP is perpendicular to the axis of the wire at P.

$$T = W.\ AP = W\ (OP - OA)$$

that is

$$T = WR\ (1 - m\cos\theta) \quad . \quad . \quad (2)$$

The single force W, acting vertically at P, produces a direct shear stress in the wire. This stress may be considered as approximately varying from 0 at the top and bottom of the wire, to $\frac{4}{3} \times \frac{W}{\frac{\pi}{4}d^2}$ or $\frac{16\,W}{3\,\pi\,d^2}$ on the horizontal diameter of the wire. As an approximation, the distribution of shear on a horizontal plane is assumed to be uniform, though, actually, the stress is probably appreciably greater near the centre of the wire than at the circumference. Figs. 3 and 4 show the values of M and T, respectively, at various points on the coil for different values of m. When m is greater than 1—that is, when the point B is outside the coils of the spring—the value of the twisting moment, T, is negative over a portion of the spring, and it becomes zero at P when BP is tangential to the coil at P. W. BP is then a pure bending moment.

For example, when $m = 2$ and $\theta = 60°$, as at x, we get

$$T = 0 \text{ and } M = \sqrt{3}\ W\ R.$$

To determine an expression for the deflection of the spring, the principle of resilience may be employed.

The torsional resilience $\delta\omega_1$ of an element δl of the wire is

$$\tfrac{1}{2} \cdot \frac{T^2\,\delta l}{N\,J},$$

where N is the torsional modulus, or modulus of rigidity of the material, and J is the polar moment of inertia of the wire, that is, $J = \frac{\pi d^4}{32}$.

But

$$\delta l = R\ \delta\theta$$

$$\therefore\ \delta\omega_1 = \tfrac{1}{2}\,\frac{T^2\,R\,\delta\theta}{N\,J},$$

and the torsional resilience of one coil $= \frac{1}{2} \cdot 2 \cdot \int_0^{\pi} \frac{T^2 R}{N J} d\theta$,

and the torsional resilience of n coils $= \frac{R n}{N J} \int_0^{\pi} T^2 d\theta$.

But $T = WR(1 - m \cos \theta)$

$$\therefore \omega_1 = \frac{W^2 R^3 n}{N J} \int_0^{\pi} (1 - m \cos \theta)^2 d\theta$$

$$= \frac{W^2 R^3 n}{N J} \left[\theta - 2m \sin \theta + m^2 \left(\frac{\theta}{2} + \frac{\sin 2\theta}{4} \right) \right]_0^{\pi}$$

$$= \frac{W^2 R^3 n}{N J} \left[\pi + m^2 \frac{\pi}{2} \right]$$

$$= \frac{\pi}{2} \cdot \frac{W^2 R^3 n}{N J} (2 + m^2) \quad . \quad . \quad . \quad (3)$$

The bending resilience of an element δl is similarly

$$\delta \omega_2 = \frac{1}{2} \frac{M^2}{E I} \delta l,$$

and the total bending resilience—substituting $R \delta\theta$ for δl—

$$\omega_2 = \frac{1}{2} \cdot \frac{R n}{E I} 2 \int_0^{\pi} M^2 d\theta.$$

But $M = W R m \sin \theta$ from (1)

$$\therefore \omega_2 = \frac{W^2 R^3 n m^2}{E I} \int_0^{\pi} \sin^2 \theta \, d\theta.$$

$$= \frac{W^2 R^3 n m^2}{E I} \left[\frac{\theta}{2} - \frac{\sin 2\theta}{4} \right]_0^{\pi}$$

$$= \frac{\pi}{2} \cdot \frac{W^2 R^3 n m^2}{E I} \quad . \quad . \quad . \quad . \quad (4)$$

The resilience due to the direct shearing force W—like that of a round shaft,* subjected to a constant shearing force W along its length—may be considered to be approximately

* Morley "Strength of Materials," p. 236.

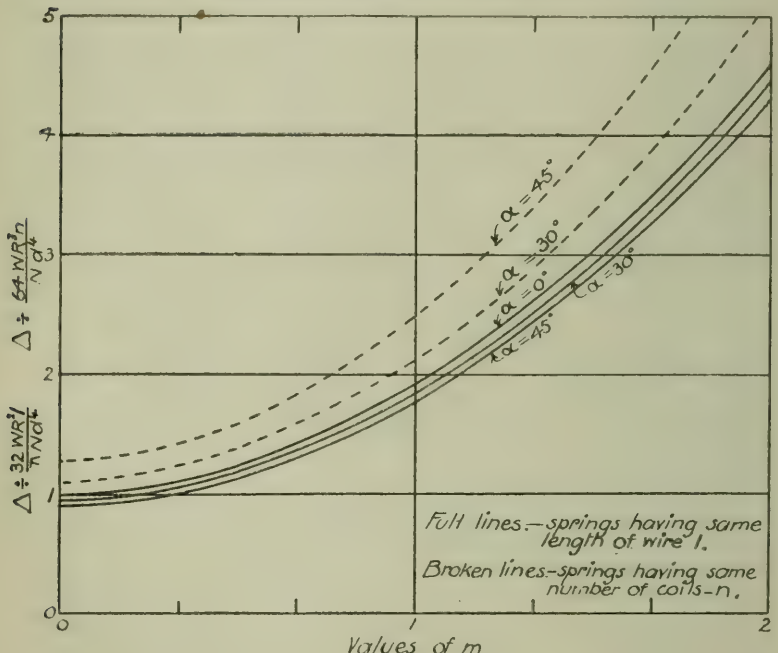
$$\omega_3 = \frac{5}{9} \cdot \frac{W^2 l\, 4}{\pi N d^2} = \frac{40}{9} \cdot \frac{W^2 R n}{N d^2} \quad . \quad . \quad (5)$$

Equating the external work done on the spring to the sum of these resiliences, we have

$$\tfrac{1}{2} W \Delta = \omega_1 + \omega_2 + \omega_3 \quad . \quad . \quad . \quad (6)$$

where Δ is the deflection of the spring, at the point of application of the load.

Fig. 5.—*Showing the Deflection Δ for different Values of m for Springs having Coils with an Obliquity of 0°, 30° and 45°.*



For the purpose of finding the deflection Δ, however, to simplify the expression, we may neglect the term ω_3 as it is small in comparison with ω_1 and ω_2

that is $\tfrac{1}{2} W \Delta = \omega_1 + \omega_2$ nearly

$$= \frac{\pi}{2} \frac{W^2 R^3 n}{N J} (2 + m^2) + \frac{\pi}{2} \frac{W^2 R^3 n m^2}{E I}$$

$$= \frac{\pi}{2} W^2 R^3 n \left\{ \frac{(2 + m^2)}{N J} + \frac{m^2}{E I} \right\}$$

Substituting $J = \frac{\pi d^4}{32}$, $I = \frac{\pi d^4}{64}$, $E = \frac{5}{2} N$ and cancelling $\frac{W}{2}$

we have $$\Delta = \frac{32 W R^2 (2 \pi R n)}{N \pi d^4} (1 + \tfrac{9}{10} m^2)$$

$$= \frac{32 W R^2 l}{\pi N d^4} (1 + \tfrac{9}{10} m^2) \quad . \quad . \quad . \quad (7)$$

where l is the length of wire in the spring.

When the load is axial, and therefore $m = 0$.

$$\Delta = \frac{32 W R^2 l}{\pi N d^4}$$

which is the usual formula.

The curve $\alpha = 0$ (where α is the obliquity of the coils) in Fig. 5 shows the extent to which the deflection of a close-coiled spring is increased as the eccentricity of the load is increased.

To determine the maximum stress in the wire.

The maximum shear stress f_s produced in the outside fibres of the wire, by a torque T, is given by the usual equation

$$f_s = \frac{16 T}{\pi d^3}$$

so that, by substitution for T from equation (2)

$$f_s = \frac{16 W R (1 - m \cos \theta)}{\pi d^3} \quad . \quad . \quad . \quad (8)$$

Similarly from the usual equation for bending $f_c = \frac{M}{Z}$

that is $$f_c = \frac{32 W R m \sin \theta}{\pi d^3} \quad . \quad . \quad . \quad (9)$$

where f_c is the maximum direct stress at the top and bottom extremities of the vertical diameter of the cross-section of the wire.

There is also a direct stress q on each section, varying from 0 at the upper and lower surfaces to about $\frac{4}{3} \cdot \frac{4 W}{\pi d^2}$ on the centre line, as mentioned above.

The maximum principal stress will, therefore, most probably occur at one extremity of the vertical diameter of the wire, and its value will be—as at these points $q = 0$

$$f = \tfrac{1}{2} f_c + \sqrt{\tfrac{1}{4} f_c^2 + f_s^2} \quad . \quad . \quad . \quad (10)$$

For small values of m the maximum principal stress may be at one extremity of the horizontal diameter of the wire, as explained later.

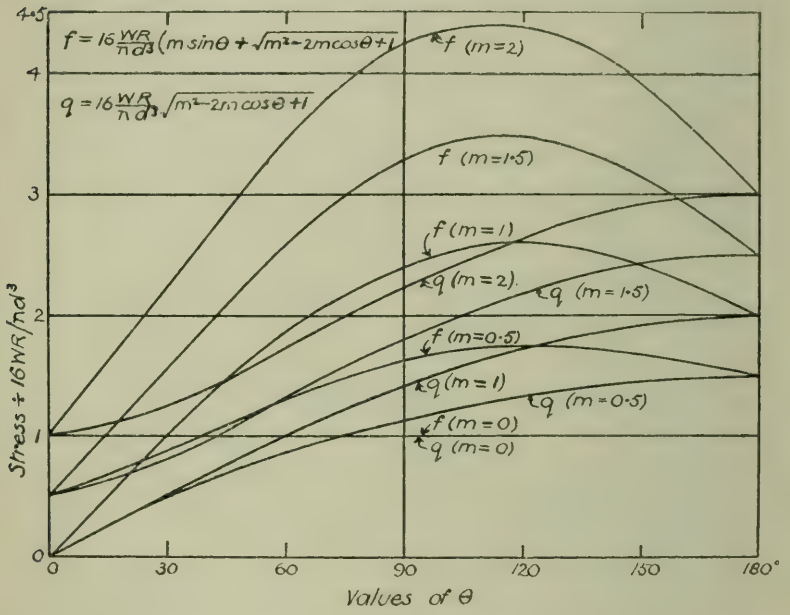
Substituting in (10) for f_s from (8) and for f_c from (9)

$$f = \frac{16\ \mathrm{W\ R}}{\pi\ d^3} \left\{ m \sin\theta + \sqrt{m^2 - 2m\cos\theta + 1} \right\} \quad . \qquad (11)$$

which reduces to $\frac{16\ \mathrm{W\ R}}{\pi\ d^3}$ when $m = 0$, for an axial load.

Fig. 6 shows, for various points on the coil, and for different eccentricities of the load, the values of the maximum principal

FIG. 6.—*Showing the Maximum Principal Stress f and the Maximum Shear Stress q, at one extremity of the Vertical Diameter of the Wire.*



stress f at the extremities of the vertical diameter of the cross section of the wire.

The same figure also shows the values of the maximum shear stress q, which occurs on planes inclined at 45° to the principal planes. These curves are derived from the usual equation

$$q = \sqrt{\tfrac{1}{4} f_c^2 + f_s^2}$$
$$= \frac{16\ \mathrm{W\ R}}{\pi\ d^3} \sqrt{m^2 - 2m\cos\theta + 1} \quad . \qquad (12)$$

This expression applies only to the top and bottom of the cross-section of the wire, and assumes the direct shear there to be zero; it has a maximum value, when $\theta = 180°$ of

$$q_{max} = \frac{16\,W\,R}{\pi\,d^3}(1 + m) \quad . \quad . \quad . \quad (13)$$

On *all* the outer fibres of the wire, however, there is a torsiona shear stress f_s due to the twisting moment; and the value of this from (8) is

$$f_s = \frac{16\,W\,R}{\pi\,d^3}(1 - m\cos\theta)$$

the maximum value occurring when $\theta = 180$,

that is $$f_{s\,max} = \frac{16\,W\,R}{\pi\,d^3}(1 + m)$$

This agrees with the expression obtained in (13) as at the point on the coil where $\theta = 180°$, the value of the bending moment M is zero, and at the top and bottom of the wire, the direct shear stress is also zero.

But on the horizontal diameter of the wire, the value of the direct shear stress is not zero, but has there its maximum value. It is probably somewhat less than $\frac{4}{3}\times$ average shear or $\frac{16}{3}\cdot\frac{W}{\pi\,d^2}$ at the extremities of this diameter.

On the inside of the coil, at the extremity of the horizontal diameter of the wire, the torsional shear stress and the direct shear stress are of the same sign, and as they act in the same plane the maximum shear stress there is

$$q_{max} = f_{s\,max} + \frac{16\,W}{3\,\pi\,d^2}$$

$$= \frac{16\,W\,R}{\pi\,d^3}(1 + m) + \frac{16\,W}{3\,\pi\,d^2} \quad . \quad . \quad (14)$$

and the latter term, though usually neglected, may have an appreciable effect.

The maximum principal stress at this point—the bending stresses being zero—is equal in intensity to the shear stress.

$$\text{that is } f = \frac{16\,W\,R}{\pi\,d^3}(1 + m) + \frac{16\,W}{3\,\pi\,d^2} \quad . \quad . \quad (15)$$

and if m is small, this may be greater than the principal stress

given by equation (11) for one extremity of the vertical diameter of the wire.

Open-coiled Helical Springs.—Let the obliquity of the coils be α to the horizontal. As before, let the load W acting at B, be replaced by the two couples W. BA and W. AP, and a direct force W at P (*see* Figs. 7 and 8.)

The couple W. AP may be resolved into two component couples.

(i) W cos α AP, acting in a plane at right angles to the longitudinal axis of the wire at P, and inclined at α to the vertical.

(ii) W sin α AP, acting in the plane which contains the longitudinal axis of the wire at P, and inclined at α to the horizontal.

Fig. 7.

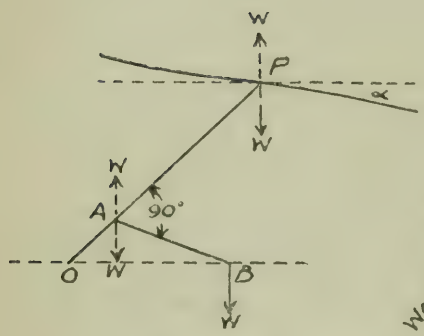
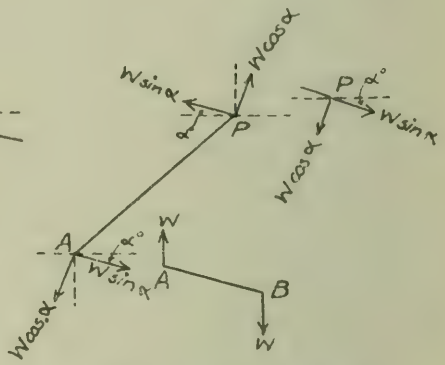


Fig. 8.



Similarly the single force W at P may be resolved into two component forces.

(i) W sin α along the wire at P.

(ii) W cos α perpendicular to the wire at P.

The original weight W at B may now be considered as equivalent to :—

(i) a direct shearing force, W cos α, at P, giving shear stresses approximately varying from 0 at the top and bottom of the wire to about $\frac{16}{3}\frac{\text{W} \cos \alpha}{\pi d^2} = q^1$ (say), on the horizontal diameter.

(ii) a direct force, W sin α, giving a stress of $\frac{4 \text{ W} \sin \alpha}{\pi d^2} = p$ say . . . . . (16)

(iii) a bending moment $M_1 = W. AB.$

$= W\ m\ R \sin \theta$ . . (17)

acting in a vertical plane tangent to the coil at P.

(iv) a bending moment $M_2 = W \sin \alpha\ AP$

$= W\ R \sin \alpha (1 - m \cos \theta)$ (18)

acting in the plane of the coil at P, that is, at α to the horizontal.

(v) a twisting moment $T = W \cos \alpha\ AP$

$= W\ R \cos \alpha\ (1 - m \cos \theta)$ (19)

acting in a plane inclined at α to the vertical, and at right angles to the longitudinal axis of the wire at P.

Let the maximum stresses due to M_1 M_2 and T be f_c^1, f_c'' and f_s respectively.

Then $f_c^1 = \frac{32 \text{ W R } m \sin \theta}{\pi d^3}$ . . . (20)

compression or tension at the top and bottom of the wire

$$f_c'' = \frac{32 \text{ W R} \sin \alpha\ (1 - m \cos \theta)}{\pi d^3} \quad . \quad . \quad . \quad (21)$$

compression or tension at the inside and outside of the wire

$$f_s = \frac{16 \text{ W R} \cos \alpha\ (1 - m \cos \theta)}{\pi d^3} \quad . \quad . \quad . \quad (22)$$

shear stress in all the outside fibres of the wire

The maximum principal stress at one extremity of the vertical diameter of the wire is,

$$f_1 = \tfrac{1}{2} (f_c^1 + p) + \sqrt{\tfrac{1}{4} (f_c^1 + p)^2 + f_s^2} \quad . \quad (23)$$

and that at the inner or outer extremity of the horizontal diameter of the wire is

$$f_2 = \tfrac{1}{2} (f_c'' + p) + \sqrt{\tfrac{1}{4} (f_c'' + p)^2 + (f_s + q^1)^2} \quad . \quad (24)$$

The maximum shear stress at 45° to the principal direct stress has values

$$q_1 = \sqrt{\tfrac{1}{4} (f_c^1 + p)^2 + f_s^2} \quad . \quad . \quad . \quad (25)$$

at the top or bottom of the wire, and

$$q_2 = \sqrt{\tfrac{1}{4} (f_c'' + p)^2 + (f_s + q^1)^2} \quad . \quad . \quad (26)$$

at the inner or outer extremity of the horizontal diameter of the wire.

The expressions in equations (23) and (24) only give the values of the principal stresses at one extremity of the vertical diameter of the wire, and at one extremity of the horizontal diameter, respectively.

The values of the principal stresses at any other point in the wire can be calculated by combining the stresses due to—

(i) the direct shearing force W cos α.
(ii) „ „ force W sin α.
(iii) the bending moment M_1 (equation 17).
(iv) „ „ „ M_2 („ 18).
(v) the twisting moment T („ 19).

at the point under consideration.

For example, it may be easily seen that, if any cross-section of the wire at right angles to the longitudinal axis of the wire is considered, it is possible, in one quadrant, for the three direct forces to be of the same sign. Considering the values of the stresses at a point on the circumference of the wire in that quadrant, at the extremity of a radius which makes an angle β with the vertical diameter, we have the following stresses :—

(i) the direct stress $p = \frac{4 \text{ W} \sin \alpha}{\pi d^2}$ as before.
(ii) „ „ „ due to M_1 that is, $f_c^1 \cos \beta$ where f_c^1 is the value in eq^n. (20)
(iii) „ „ „ due to M_2 that is, $f_c'' \sin \beta$. where f_c'' is the value in eq^n. (21)
(iv) the stress due to the direct shearing force, which is approximately equal to $q^1 \sin^2 \beta$ where $q^1 = \frac{16}{3} \cdot \frac{\text{W} \cos \alpha}{\pi d^2}$ acting vertically.
(v) the shear stress f_s due to the twisting moment T, having the value given in equation (22), and acting tangentially that is, at β to the horizontal.

Combining (iv) and (v), the resultant shear stress on the cross section, at the point under consideration, is

$$f_s^1 = \sqrt{(f_s^2 + q^{1^2} \sin^4 \beta) + 2 f_s q^1 \sin^3 \beta} \quad . \quad . \quad (27)$$

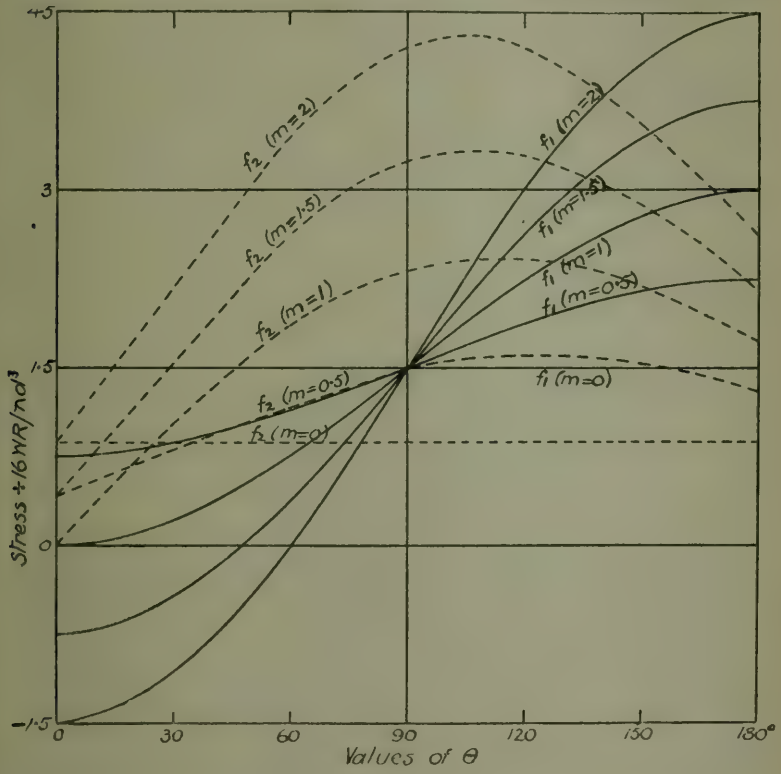
and the maximum principal stress at the point is

$$\tfrac{1}{2}(p + f_c^1 \cos\beta + f_c'' \sin\beta) + \sqrt{\tfrac{1}{4}(p + f_c^1 \cos\beta + f_c'' \sin\beta)^2 + f_s^{1\,2}} \quad . \quad (28)$$

while the maximum shear stress at the point is

$$\sqrt{\tfrac{1}{4}(p + f_c^1 \cos\beta + f_c'' \sin\beta)^2 + f_s^{1\,2}} \quad . \quad (29)$$

FIG. 9.—*Showing the Values of the Principal Stresses f_1 and f_2, when $\alpha = 30°$.*



Generally, however, f_1 (equation 23) is the largest principal stress in the material, except when α is very small and the eccentricity of the load small, as in Fig. 10 (page 885), when f_2 may be the greatest.

Fig. 9 (page 881) shows the values of f_1 and f_2, when the obliquity of the coils $\alpha = 30°$, p and q being neglected.

Deflection.—The deflection of an open-coiled spring, at the point of application of the load, may be estimated from the resilience of the spring, by the same method that was adopted for the close-coiled spring.

The length of one coil $= 2\pi \mathrm{R} \sec\alpha$

and $\delta l = \mathrm{R} \sec\alpha \, \delta\theta$.

If, for the sake of comparison, the total length, l, of wire in the spring, is considered to be equal to that taken for the close-coiled spring, then the number of coils will be $n \cos\alpha$.

that is $l = (2\pi \mathrm{R} \sec\alpha) \times (n \cos\alpha) = 2\pi \mathrm{R}\, n$.

The resilience of the spring due to the direct stress, p, is

$$\frac{1}{2} \cdot \frac{p^2}{\mathrm{E}} \times (\text{volume of wire})$$

$$= \frac{1}{2\mathrm{E}} \left(\frac{4 \mathrm{W} \sin\alpha}{\pi d^2} \right)^2 \left(\frac{\pi d^2}{4} \cdot 2\pi \mathrm{R}\, n \right)$$

$$= \frac{4 \mathrm{W}^2 \sin^2\alpha \, \mathrm{R}\, n}{\mathrm{E}\, d^2}$$

or $\dfrac{2 \mathrm{W}^2 \sin^2\alpha \, l}{\mathrm{E}\, \pi d^2}$

and that due to the direct shearing stress q is approximately

$$\frac{20}{9} \cdot \frac{\mathrm{W}^2 \cos^2\alpha \, l}{\pi \mathrm{N} d^2} \text{ or } \frac{40}{9} \cdot \frac{\mathrm{W}^2 \cos^2\alpha \, \mathrm{R}\, n}{\mathrm{N} d^2}$$

a similar result to that given in equation (5).

The values of both these expressions are small, and they may usually be neglected, unless very accurate results are required.

Neglecting these values, then, we have—

$$\frac{1}{2} \mathrm{W} \Delta = \frac{\mathrm{R}\, n}{\mathrm{N}\, \mathrm{J}} \int_0^\pi \mathrm{T}^2 \, d\theta + \frac{\mathrm{R}\, n}{\mathrm{E}\, \mathrm{I}} \int_0^\pi \mathrm{M}_2{}^2 \, d\theta + \frac{\mathrm{R}\, n}{\mathrm{E}\, \mathrm{I}} \int_0^\pi \mathrm{M}_1{}^2 \, d\theta$$

$$= \frac{\mathrm{W}^2 \mathrm{R}^3 n \cos^2\alpha}{\mathrm{N}\, \mathrm{J}} \int_0^\pi (1 - m \cos\theta)^2 \, d\theta + \frac{\mathrm{W}^2 \mathrm{R}^3 n \sin^2\alpha}{\mathrm{E}\, \mathrm{I}} \int_0^\pi (1 - m \cos\theta)^2 \, d\theta$$

$$+ \frac{\mathrm{W}^2 \mathrm{R}^3 n}{\mathrm{E}\, \mathrm{I}} \int_0^\pi m^2 \sin^2\theta \, d\theta$$

$$= \frac{W^2 R^3 n \cos^2 \alpha}{N J}\left\{\frac{\pi}{2}(2 + m^2)\right\} + \frac{W^2 R^3 \sin^2 \alpha\, n}{E I}\left[\frac{\pi}{2}(2 + m^2)\right] + \frac{W^2 R^3 n m^2 \pi}{E I 2}$$

that is $\frac{1}{2} W \Delta = \frac{W^2 R^3 n \pi}{N J 2}\left[\cos^2 \alpha (2 + m^2) + \frac{4}{3} \sin^2 \alpha (2 + m^2) + \frac{4}{3} m^2\right]$

cancelling $\frac{1}{2}$ W throughout,

$$\Delta = \frac{32 W R^2 l}{N \pi d^4}\left[\frac{8 (1 + m^2) + \cos^2 \alpha\ (2 + m^2)}{10}\right] \quad . \quad . \quad (30)$$

Fig. 5 (page 874) shows, for various values of m, the values of the deflection Δ when $\alpha = 0°$, $\alpha = 30°$, and $\alpha = 45°$ respectively.

It will be noticed that, for the same value of m, the deflection is smaller with an open-coiled spring than with a close-coiled spring containing the same length of wire. If the number of coils is the same for each spring, then, for the same value of m, the deflection is greater with an open-coiled spring than with a close-coiled spring, as is shown by the broken lines in Fig. 5. These curves are obtained from equation (30) by multiplying the expression by sec α.

Example: To illustrate the above notes, a helical spring composed of 0·175 inch diameter wire, and having 8 coils each with a mean diameter of 1·4 inch, will be considered. If the mean length of the spring is 3 inches, then, approximately

$$\sin \alpha = 0{\cdot}0850$$
$$\cos \alpha = 0{\cdot}9963.$$

The direct shearing stress, q, has a maximum value on the horizontal diameter of the wire, and at the extremities of the diameter the value is rather less than

$$q^1 = \frac{16 W \cos \alpha}{3 \pi (0{\cdot}175)^2} = 55{\cdot}5 \text{ W (say) lb. per sq. inch.}$$

The direct force W sin α produces a direct stress of

$$p = \frac{4 W 0{\cdot}085}{\pi (0{\cdot}175)^2} = 3{\cdot}53 \text{ W lb. per sq. inch.}$$

The deflections, shown in Fig. 10, are calculated from equation (7) which reduces to

$$\Delta = 0{\cdot}0156 \text{ W } (1 + 0{\cdot}9\, m^2)$$

or from equation (30) which reduces to

$$\Delta = 0{\cdot}0156\ \text{W}\ (0{\cdot}9985 + 0{\cdot}899\ m^2).$$

The values therefore differ by

$$0{\cdot}0156\ \text{W}\ (0{\cdot}0015 + 0{\cdot}001\ m^2)$$ approximately,

which even when $m = 2$ only amounts to 0·000086 W—an indistinguishable amount in the figure.

The deflections due to the direct stress p, and to the direct shear stress q_1 are both negligible, the latter and larger of these being only about 0·000135 W inch.

The error introduced, by neglecting both these terms is, in this example, less than 1 per cent. when the load is axial, and less than $\frac{1}{2}$ per cent. when $m = 1$.

The values of the stresses in the wire, calculated by the various formulæ stated, are tabulated below, and plotted in Fig. 10.

	f (11)	q (13)	q (14)	f_1 (23)	f_2 (24)	q_1 (25)	q_2 (26)
$m = 0$	665W	665W	720·5W	665W	779W	663W	721W
0·5	1166W	997·5W	1053W	1168W	1140W	878W	1053W
1·0	1728W	1330W	1385W	1728W	1500W	1150W	1385W
1·5	2314W	1662W	1718W	2314W	1861W	1448W	1718W
2·0	2912W	1995W	2050W	2912W	2222W	1758W	2050W

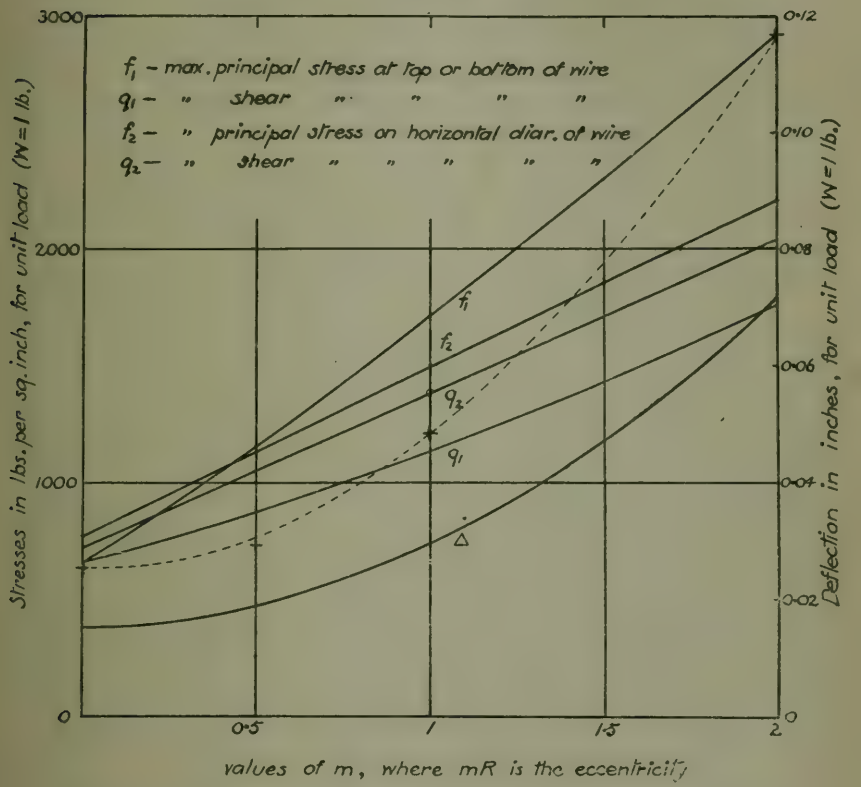
It may be clearly seen then, that unless the load is axially applied upon a spring, the stresses may be considerably greater than those for which the spring was designed.

In the worked example, for instance, 665 W would represent the load for which the spring was probably designed, that is, assuming axial loading and neglecting the direct shear stress, whereas the maximum shear stress even with axial loading is 721 W, and the maximum principal stress f_2 is 779 W.

With an eccentricity of 0·5 R, which could easily occur, the maximum shear stress is about 1053 W and the maximum principal stress f_1 about 1168 W.

If the eccentricity of the load is greater than 0·5 R the stresses are still more in excess of the nominal safe load for axial loading. It is very important, therefore, that the ends of springs should be so designed as to ensure axial loading. This is moderately simple for tension springs, but compression springs present more

FIG. 10.



difficulty: unfortunately, too, the deformation of a spring under an eccentric compressive load, tends to increase the eccentricity, and therefore still further to increase the stresses.

This increase of eccentricity has not been considered in the above calculations.

Experimental Results.—The following experiments were undertaken in order to test the truth of the general formula (30) for the deflections caused by eccentric loads.

A horizontal Buckton machine was used for the tests, and the loads were transmitted to the spring through knife-edges. The degree of eccentricity could thus be accurately measured, and the spring was allowed to deflect freely. The deflections were measured by means of a pointer and scale fixed to the bearing plates of the machine, the readings being taken to the nearest 0·01 inch. A preliminary experiment was made in order to deduce the difference between the effective number and the actual number of coils in compression springs.

A set of six small springs was taken, the number of coils varying from about $4\frac{1}{2}$ to nearly 20: the diameter of coil was the same in each case, as was also the gauge of the wire. A number of axial loads were applied by hand to each spring in turn, and the corresponding deflections measured by sighting to a finely divided scale through a theodolite telescope. Graphs were drawn, and the mean deflection of each spring, produced by a load of 1 lb., was determined. These values were then plotted as ordinates against abscissæ proportional to the number of coils. Fig. 11 (page 887) shows that a straight line could be drawn through the points thus located, and that when this line was produced backwards, it cut the axis at a point corresponding to 1·5 coils. Thus, in the case of a compression spring, the effective number of coils is apparently found by deducting 1·5 from the actual number. In a tension spring the two values are identical.

The large spring tested for eccentric loading had the following dimensions:—

Actual number of coils . .	8
Effective „ „ . .	$6\frac{1}{2}$
Mean diameter „ .	7·245 inches.
„ „ of wire . .	0·755 „
Length of spring unloaded .	18 „
$\cos \alpha$ . . .	0·993 approx.
$\cos^2 \alpha$	0·986 „

Fig. 11.

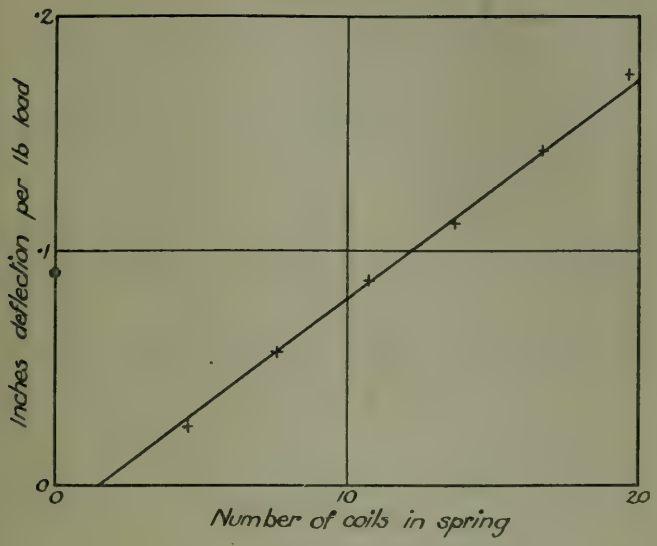
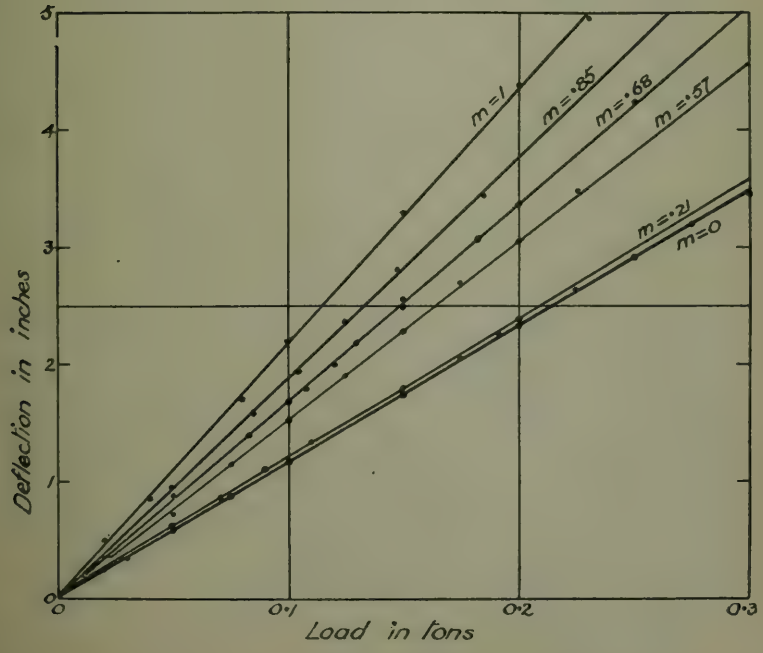
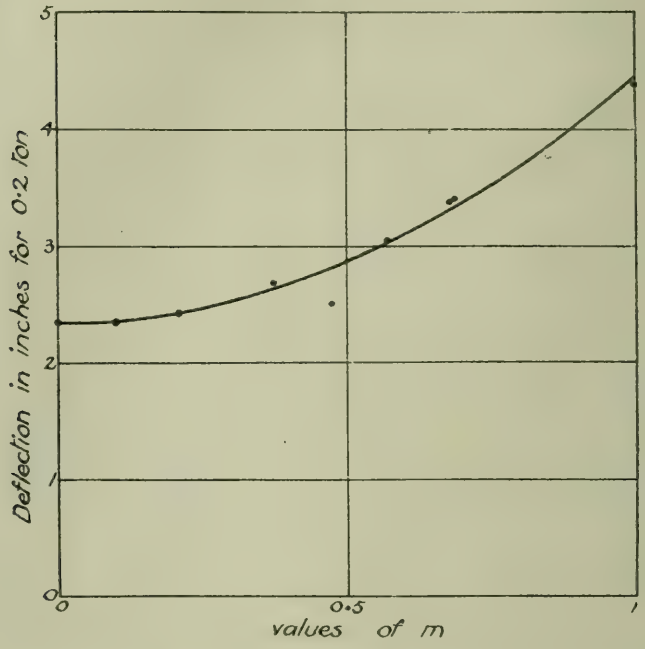

·2
·1
0
Inches deflection per lb load
0
10
20
Number of coils in spring

Fig. 12.


5
4
3
2
1
0
Deflection in inches
m=1
m=·85
m=·68
m=·57
m=·21
m=0
0
0·1
0·2
0·3
Load in tons

Actually the value of $\cos^2 \alpha$ varies as the spring is compressed, and would be roughly 0·991 when the deflection was 4 inches, but the effect upon the deflection calculated from (30) is very small. Fig. 12 (page 887) shows a number of graphs plotted from the experimental results, and depicts the relationship between deflection and load for various values of m (where mR is the eccentricity).

Fig. 13.



Other results were obtained, but to avoid confusion they have been omitted from the diagram.

From the graphs for each set of readings, the mean deflection due to a load of 0·2 ton was deduced, and the results plotted in Fig. 13. The full line in this figure is the theoretical curve deduced by means of formula (30) and the experimental value of the deflection produced by the axial load. It agrees very closely with the points obtained by experiment.

The modulus of shear N, may be deduced from equation (30) by substituting $\delta = 2{\cdot}33$ inches, $W = 0{\cdot}2$ tons, $l = 149$ inches, $m = 0$ and $\cos^2 \alpha = 0{\cdot}9862$. That is—

$$N = \frac{32 \times 0{\cdot}2 \times (3{\cdot}622)^2 \times 149}{2{\cdot}33 \times 3{\cdot}1416 \times (0{\cdot}755)^4} \left\{ \frac{8 + (2 \times 0{\cdot}9862)}{10} \right\}$$
$$= 5{,}270 \text{ tons per square inch, roughly.}$$

The deflection of a smaller spring, somewhat similar to that considered in the worked example, was also tested experimentally —the eccentricity varying from $m = 0$ to $m = 5$. The results agreed almost exactly with the theoretical curve partly shown by the dotted line in Fig. 10 (page 885). The spring in this case had eight effective coils with an external diameter of 1·6 inches, and the wire was 0·16 inch in diameter.

The Paper is illustrated by 13 Figs. in the letterpress.

* PRISM-HARDNESS :

A NEW METHOD OF TESTING HARDNESS IN MATERIALS; YIELDING A SCALE THAT IS EQUALLY APPLICABLE TO THE HARDEST AND SOFTEST METALS, AND EXPRESSES THE VALUES IN UNITS OF STRESS.

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[*Selected for Publication.*]

Definition of Hardness.—The utility and popularity of the term "hardness" may be attributed, in part, to the flexibility of its meaning, which varies for different materials according to their applications in the Arts and Crafts. A hard bearing alloy and a hard carbon brush are hard in different senses, the one signifying resistance to flow under crushing stress, and the other resistance to abrasion. More commonly, as in diamond, tool-steel, and cast-iron, hardness relates to the processes of scratching, cutting or penetration.

Probably on account of this flexibility of meaning, the term has eluded scientific definition. Hardness seldom, if ever, signifies a single physical property of material; and it is improbable that any physical definition of the term—even if generally accepted—could fulfil all the varied functions of the current meanings. Any definition, to be serviceable in practice, must recognize the empirical nature of the quantity and admit the use of different scales to suit the different meanings of the term.

* Awarded a Prize of £25 by the Sir Robert Hadfield Prize Committee.
[The I.Mech.E.]

A definition which includes most of the current meanings and indicates the common characteristic of hardness tests, may be expressed as follows: The hardness of a material may be defined as a measure of its resistance to the complex and often indefinite stresses—complex in nature, whether compressive or shearing, and variable in magnitude and distribution—that are called into play in the course of *specific operations* such as scratching, abrasion, cutting, and penetration.

According to this definition, any given material may have many different hardness values, corresponding to the many operations that are met with in processes of manufacture or service, or in arbitrary methods of testing. A pair of materials may indicate different relative hardnesses on different scales, according to the natures of the operations adopted as the experimental bases of the corresponding tests. The value of any particular scale of hardness, as a guide in practice, depends on the degree of similarity between the process adopted in the test and the working conditions under which the material is used in manufacture or service. Although a limited degree of similarity may inspire some measure of confidence, nothing short of experience or research can demonstrate the validity of any particular hardness test as a guide for any particular class of service.

Research has shown that certain hardness scales are of service as indicating the approximate tensile yield-point and ultimate strength, as well as the crushing strength of the materials tested. To facilitate the tabulation of factors connecting these quantities it is desirable, although not essential, that hardness and strength should be measured in the same units, those of stress—tons per square inch or kilograms per square millimetre.

Although the use of consistent units facilitates the comparison of data from different sources and is, therefore, advantageous, it is still more important that the method of testing and the method of computation—adopted in the determination of empirical hardness values—shall be so related that the resulting values are, as far as possible, independent of the incidental conditions of the test, that is, independent of the dimensions of the test-piece and the tool, and

the magnitude of the load or blow employed in making the test. Failing such correlation, comparisons between data from different sources may prove misleading.

Principles Relating to a New Test of Hardness.—In endeavouring to devise an improved method of gauging hardness in metals, the Author drew up a summary of the fundamental principles involved. This is given below, with brief notes that indicate the bearing of the principles on the novel test described.

(1). Since surface hardness varies widely and affords little indication of that body-hardness which is generally more important, it is considered that the penetration method of testing—producing moderately deep indentations—is preferable to methods in which the surface is only lightly scratched or otherwise deformed. Indentation is a simple process and requires only a minimum of skill in its performance and measurement. On the other hand, indentation is possible only when the metal is endowed with some degree of ductility. Brittle metals, whether hard or soft, may crack before suffering measurable indentation.

(2). The test should be widely applicable, not only for structural metals of moderate hardness, but also for the hardest steels such as, at present, are difficult to test. Hardness being, indeed, more important in tool-steels than in structural metals, it is particularly desirable that the test should discriminate between superhard metals. Moreover, in order to compare the qualities of high-speed tool-steels under working conditions, the test should be such as can be carried out at high temperature.

The most obvious limitation to indentation tests, as at present performed, being the inability of the indenting tool—whether prism, ball or cone—to stand the loads required to produce deep indentations in materials as hard as or harder than itself, it occurred to the Author that a pair of test-pieces of the same material might be used to indent one another. Both pieces of the test sample would be deformed in the test, and either indentation would afford a measure of the common hardness. The test-pieces might be alike in form or different. A variety of forms might be used, for example, prisms, spheres, or cylinders.

(3). As superhard metals are commonly more or less brittle, the manner of indentation should be such that fairly large impressions are obtained without undue displacement of metal. And since brittleness is most apparent under tension, the form of test-piece and the method of loading should be such that the heavier stresses, occurring near the indentation, should act chiefly as compression combined with shear. As tensile stresses must occur in other parts of the test-piece, the indentations, in brittle materials, should not be too large in proportion to the dimensions of the test-piece. In the case of a test in which two pieces of the same material indent one another, it is probable that the displacement of metal is a minimum when the two pieces are alike in form.

(4). In order that the test may be directly comparable with the conditions of service of hard metals, and thereby afford a rational indication of relative hardness, the form of the test-piece and the method of loading should approximate to the conditions of action of cutting tools.

The indentation of a pair of cutting edges, by mutual pressure, suggests itself as comparable with such conditions. Fig. 1 indicates the method suggested. Two square prisms, placed crosswise with their edges in contact, are pressed together by a measured load. Alternatively, a pair of cylinders may be pressed together in the same manner, although, as will be explained, prismatic test-pieces offer considerable theoretical advantages.

(5). The test-pieces should be of simple form, with surfaces that can be finished, when necessary, by grinding. Although the simplicity of the Brinell and Shore test-pieces can hardly be attained in any test that requires a pair of samples, a fair degree of convenience may be obtained by using square prisms. In superhard materials, such prisms are readily finished by grinding.

To avoid the need for preparing special test-pieces, it is convenient to use the broken ends of Izod impact test-pieces—already machined as square prisms with 10 mm. side. In special circumstances, for example, in testing hard-drawn wire, it is convenient to use cylindrical test-pieces.

(6). To ensure that the hardness value indicated by a penetration

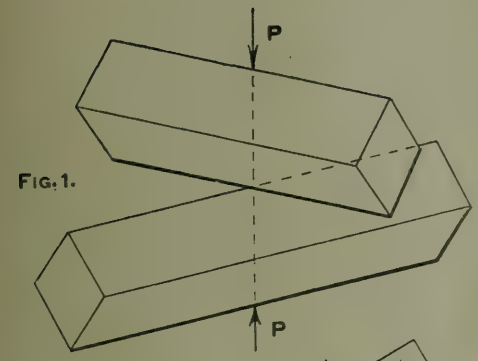


FIG. 1.

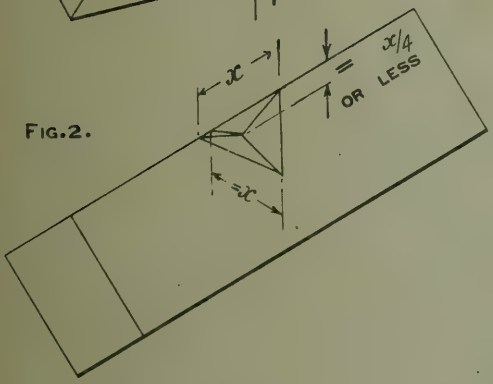


FIG. 2.

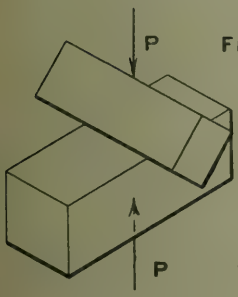
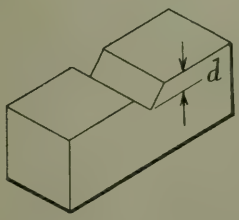
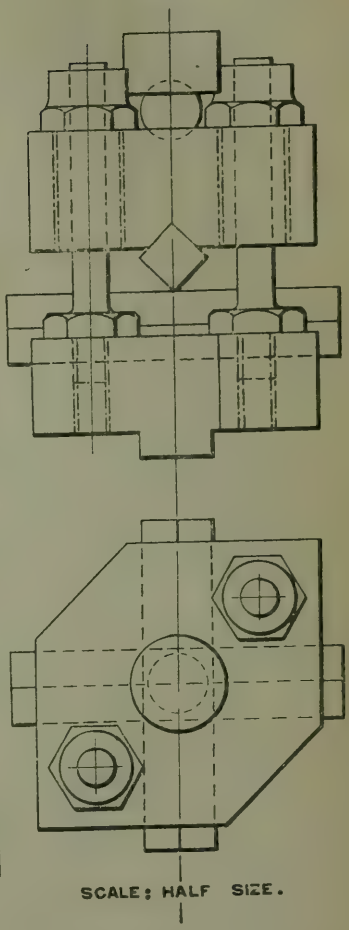


FIG. 3.



Jig to hold Test-pieces.

FIG. 4.



SCALE: HALF SIZE.

test does not vary with the load applied, the form of indentation must not vary, although its size increases, with the load. In terms of the hardness definition suggested above, the " specified operation " should be the same no matter what load is applied. As is well known, this condition is admirably fulfilled in the Ludvik cone test; but not in the Brinell ball test, in which latter, consequently, the hardness value varies with the load applied in making the test.

In the prism-test proposed, the form of indentation—shown diagrammatically in Fig. 2—is quite independent of the load. Provided that the indentation is not too large in proportion to the dimensions of the test-piece, the ratio between any pair of linear dimensions remains unchanged for different loads on a homogeneous material. This condition being fulfilled, we may apply the principle of similarity enunciated by Professor James Thomson* and extended by Professor Archibald Barr.† Similar bodies of homogeneous material are alike severely stressed and strained, whether within or beyond the elastic limit, by loads proportional to the squares of the linear dimensions, provided that these loads are applied in the same manner and similarly distributed. As a corollary to this theorem, it follows that the loads required to produce similar indentations in large bodies of homogeneous material are proportional to the squares of the linear dimensions of the indentations.

In the prism test described, consistent hardness values may, therefore, be deduced by dividing the applied loads by the squares of any characteristic linear dimension of the indentations produced, width or depth, according as the one or other may be preferred.

Width and depth both offer certain advantages in the case of the prism-indentation. Depths may be measured while the test-pieces are still under load; and a series of readings may be taken under successive loads. Widths can be measured, however, with greater inherent accuracy, and may be remeasured at any time after the test-pieces have been taken out of the testing-machine. As will be shown later, width offers the further advantage that the

* Journal, Inst. of Engineers and Shipbuilders in Scotland, 21st Dec. 1875.

† *Ibid.* 21st March 1899.

resulting hardness value is practically independent of the angle of the prism within broad limits.

In the tests described in the following pages, the Author measured the width of the indentation from corner to corner along the cutting edge (x, Fig. 2), and used this as the characteristic linear dimension of the indentation due to the measured load, P. "Prism hardness" is thence defined as the quotient

$$\text{"PH"} = \frac{P}{x^2},$$

which may be expressed in units of tons per square inch or kilograms per square millimetre. For example, a load of 4 tons, giving an indentation with a width $x = 0{\cdot}2$ inch, would indicate a prism hardness of

$$\text{"PH"} = \frac{4 \text{ tons}}{(0{\cdot}2)^2 \text{ in.}^2} = \frac{100 \text{ tons}}{\text{in.}^2} = \frac{157 \text{ kg.}}{\text{mm.}^2}.$$

It may be observed that the proposed test bears a superficial resemblance to that described in 1897 by Dr. W. C. Unwin *. In that well-known test, illustrated in Fig. 3, the rectangular test-piece is indented by steady pressure applied through a prismatic tool of hardened steel, ground to a 90° cutting edge. The indentation occurs only in the rectangular test-piece, the tool itself being unaffected. The load, P, and depth of indentation, d, follow an empirical relation $P = C.d^{1\cdot2}$, where C is nearly constant for different loads and may be regarded as a measure of the hardness of the metal. As is well known, Unwin's test was the pioneer of all penetration tests using steady loads. The author's test differs in two fundamental respects, namely, the two pieces of metal are both taken from the sample under test, and are shaped so that the linear dimensions of the indentation are proportional to the square root of the load that is applied in making the test.

Apparatus Used in Prism-Hardness Test.—Like other penetration tests, the crossed-prism test may be carried out in any small compression testing-machine. The auxiliary apparatus required includes a microscope with eyepiece scale, or other means of

* Proceedings, Inst. C.E., Vol. 129, Part 3.

measuring the indentation, and a jig to hold the test-pieces in the correct relative position.

Fig. 4 and Fig. 5, Plate 12, show a jig comprising two blocks cut with 90° V-grooves to suit square test-pieces, and guided so that the cutting edges of the two prisms cross one another at right-angles. The guides are a pair of steel pins, screwed into the lower block and working through long brass bushes in the upper block. To minimize friction and ensure axial loading, the load is applied through a $\frac{5}{8}$-inch steel ball that rests in spherical seatings in the upper holder and cap.

Fig. 6, Plate 12, shows the apparatus in place in a standard 3,000 kg. Brinell testing-machine. A Buckton 5-ton single-lever machine has, however, been used by the Author in nearly all the tests described in following pages. The load was then applied as follows :—The balance weight having been run out to about three-quarters of the intended load, the beam was " floated " by load applied through the test-pieces. The load was then increased gradually. After 30 seconds at the intended load, the balance weight was run back gently.

Four to six indentations were usually made with different loads on each pair of test-pieces, 3 inches in length. A hardness value was deduced from each indentation, and the several values were found in close agreement. In practice, a single indentation should suffice in nearly all cases.

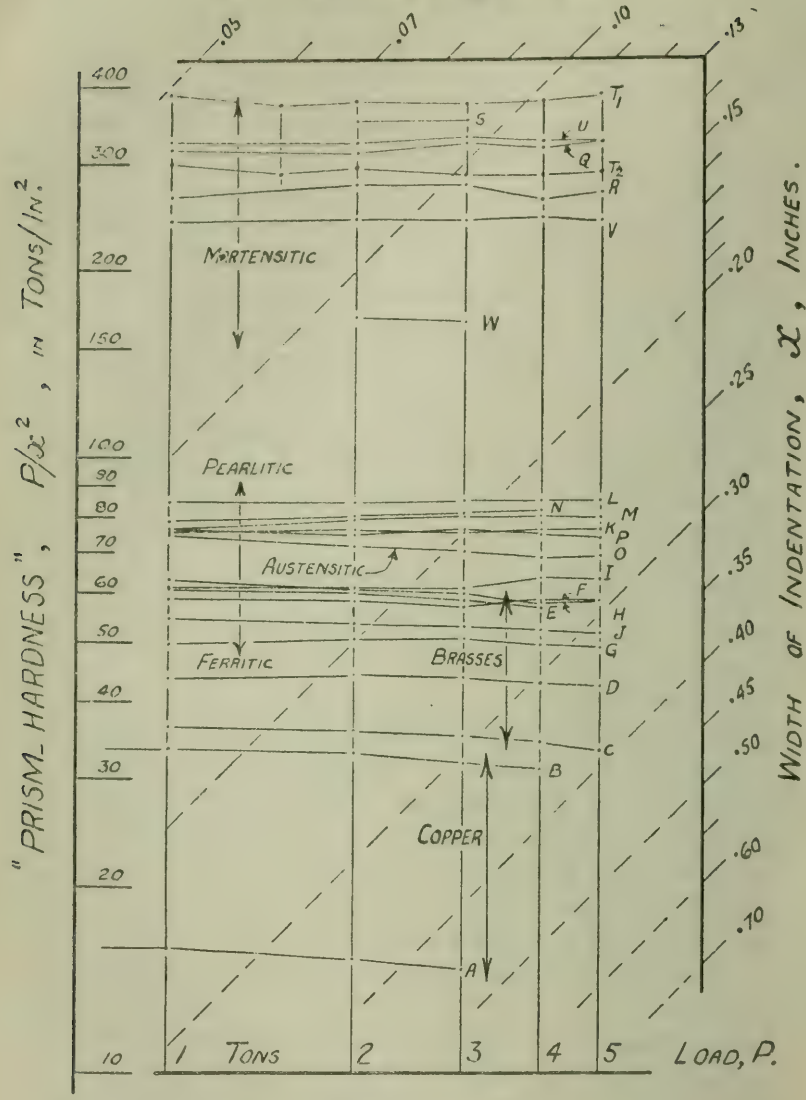
The widths of indentation were measured, after the test-pieces had been removed from the jig, by means of a microscope fitted with micrometer traversing mechanism, as shown in Fig. 7, Plate 12. In practice, a simpler method would, doubtless, suffice. The microscope was fitted with a collimator eyepiece and 15 mm. objective, giving a 2-mm. field of view with fifty-six magnifications. The appearance of the field, showing the eye-piece graticule, is represented in Fig. 8, Plate 12. It is probable that the average variance of measurement was about 0·01 mm., equivalent to $\frac{1}{2}$ per cent on a 2-mm. indentation, corresponding to 1 per cent on the hardness value determined from an indentation of this comparatively small size.

The steel test-piece shown in Fig. 8 has a moderately sharp edge. Sharper edges are readily obtainable, but are not essential except in the hardest metals that take only small indentations under loads up to 5 tons. Soft and moderately hard steels, taking indentations from 3 to 7 mm. in width, were finished on rough emery, while harder steels were finished on finer grades. A tooled or rough ground finish should suffice in practice. As will be shown later, it is not essential that the angle of the prism should be exactly 90°. Provided that the faces of the test-piece are reasonable plane, consistent results are obtained although the prism-angle may vary appreciably.

Experiments on Different Metals.—Fig. 9 (page 900) summarizes the results of a number of prism-hardness tests on different metals. Each pair of prisms, cut from different samples, was tested under different loads as scaled along the base of the diagram. The ordinates give the corresponding hardness values, "PH" $= \frac{P}{x^2}$. As both scales are plotted logarithmically, a series of diagonal lines serves to indicate the widths of indentation, x, observed in different experiments.

The diagram indicates that the hardness value of any particular sample is almost independent of the load used in making the test. Minor discrepancies, however, are apparent and fall into two categories:—(1) In the lower part of the diagram, relating to the softer metals, the hardness value tends to fall as the load increases. Thus, in soft copper, graph A, the value falls from 16·0 to 14·6 tons/in.^{2} with loads increasing from 1 to 3 tons, a change of nearly 10 per cent, although the values at 10 and 20 cwts. are nearly identical. This variation is attributed to the use of comparatively small test-pieces ($\frac{1}{2}$ inch square), too small in proportion to the large indentations formed in soft metals by heavy loads. In this soft copper, the width of indentation under 3 tons was 0·453 inches = 90 per cent of the side of the prism. To ensure that the indentations under different loads are similar, and the corresponding hardness values consistent, it would appear desirable to limit the width of indentation to not more than half the side of the prism. (2) In several instances, small

Fig. 9.—*Experiments on Different Metals.*



A	Copper, Anld.	I	0·18 % C Quenched.	Q	C.Chr.St. Quenched.
B	do. Hard drawn.	J	Mild-Steel, Rolled.	R	do. Q & T.
C	Naval Brass 60/39/1	K	Bessr. St. do.	S	1½ % C. Glass-hard.
D	Delta IV	L	do. Overstrained.	T	Knife-edges
E	do II	M	Spring steel } soft.	U	Ni-Chr. St. Quenched
F	do I	N	Silver steel }	V	do. Q & T.
G	Mild Steel Forged.	O	Era Mang. Steel.	W	do. Tempered
H	0·18 % C. Q & T.	P	C.Chr. steel, forged.		

but consistent variations of hardness may be attributed to non-homogeneous structure in the metal. Under light loads, the hardness value is determined, chiefly, by metal near the edge of the prism. Heavier loads strain deeper zones of underlying metal. The majority of the test-pieces having been cut from $\frac{1}{2}$-inch or $\frac{5}{8}$-inch square rolled bars, the corners may have been harder on account of over-rolling or softer owing to loss of carbon in steel or zinc in brass. In one or two instances, examined under the microscope, loss of carbon was clearly evident. Test-pieces cut from larger blocks showed no such variations.

It is considered that the experimental results support the application of Thomson's principle of similarity. No matter how small the load may be, indentation occurs in precisely the same manner—provided that the metal is homogeneous and the edges of the prism correspondingly sharp—and a correspondingly small quantity of metal is strained as severely as in tests under heavier loads. The character of the deformation does not depend upon the load applied.

The form of indentation varies, however, in different metals and with the heat treatment, and affords additional information regarding the nature and state of the metal. In the Brinell test likewise, the deformation of the metal surrounding the indentation varies in different metals; but the variations are less consistent because, in Brinell tests, the deformation varies also with the depth of the indentation. In certain metals, for example, soft copper and austenitic steel, the edges of the indentation are depressed below the level of surrounding metal which is raised above the original surface. This type of displacement spreads to a considerable distance, so that comparatively large volumes of metal are overstrained and, presumably, hardened. In other metals, for example, hard-drawn copper and martensitic steel, the displacement is more local, and the edges of the indentation are heaped up instead of being depressed. The contrast is illustrated in Figs. 10 and 11, Plate 13, which show the indentations of annealed and hard-drawn copper respectively. Although it appeared, at first sight, that the form of indentation was purely arbitrary, inspection showed that the

indentations of different metals could be classified in a well-defined sequence, as follows :—

Annealed copper Austenitic steel	Capable of being further hardened by overstrain.
Delta I and IV, Naval brass Delta II Ferritic steels Pearlitic steels	Intermediate.
Hard-drawn copper Martensitic steels	Fully hardened.

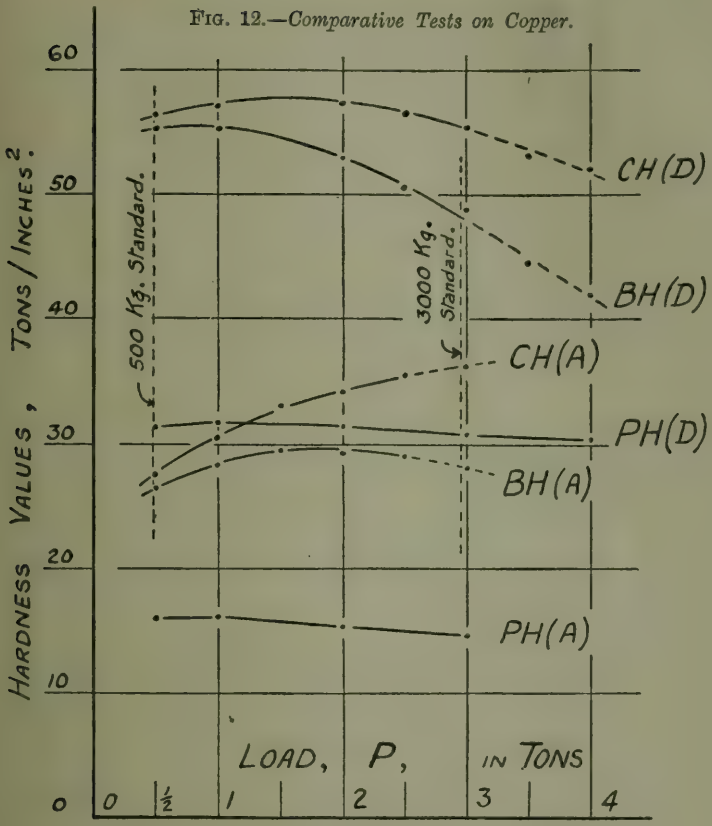
It was observed that the form of indentation was related, not to the actual hardness of the metal, but rather to its capacity for being further hardened by mechanical overstrain. Thus " Era " manganese steel and normalized 0·6 per cent carbon steel, although nearly alike in hardness $\left(\frac{P}{x^2} = \frac{70 \text{ tons}}{\text{in.}^2}\right)$, showed markedly different indentations.

It is probable that the form of the indentation affords a simple qualitative means of anticipating certain characteristic properties of the metal, particularly its capacity for being further hardened by mechanical treatment and, as a consequence, the form of the stress-strain diagram for ductile strain. Pending further investigation, it may be anticipated, also, that the form of the indentation will afford a serviceable indication of the factors that may be applied to estimate, from the measured prism-hardness, the probable tensile yield-point, ultimate strength, etc.

Comparative Tests on Copper (Fig. 12).—In these experiments, samples $\frac{1}{2}$ inch square were cut from a single $\frac{5}{8}$-inch square bar of hard-drawn copper. Two series were tested, hard-drawn as received (D) and fully annealed (A). In each series, comparative Brinell- and Prism-hardness tests were made with different loads. The results obtained by the prism method are as follows (plotted in graphs " PH ") :—

Load.	Tons.	½	1	2	3	4
" PH " (D)	$\frac{\text{tons}}{\text{in.}^2}$	31·3	31·8	32·4	(30·8)	(30·4)
" PH " (A)	$\frac{\text{tons}}{\text{in.}^2}$	16·0	16·1	(15·3)	(14·6)	—

Fig. 12.—*Comparative Tests on Copper.*



PH Prism-Hardness, P/x^2;

BH Brinell Ball-Hardness, $P \div$ Area of Indentation;

CH Modified Ball-Hardness, $P \div \frac{\pi}{4} d^2$, 10 m.m. Ball.

(BH & CH, as well as PH, expressed in Tons per Sq. Inch)

D Hard-Drawn Copper;

A Same Copper, Annealed.

Cutting out the results obtained with the heavier loads (on account of the unduly large size of the indentations) the probable hardness values are 31·5 and 16·0 tons per sq. inch, indicating that the drawn metal is 96 per cent harder than the annealed.

Brinell tests, using a standard 10 mm. ball, gave the following results :—

Load. Tons.	½	1	1½	2	2½	3	3½	4
"BH" (D) $\frac{\text{tons}}{\text{in.}^2}$	55·3	55·3	—	53·0	50·6	48·9	44·7*	42·0*
"BH" (A) $\frac{\text{tons}}{\text{in.}^2}$	26·5	28·3	29·6	29·2	29·0	28·2*	—	—
Ratio $\frac{(D)}{(A)}$	2·09	1·95	—	1·81	1·74	1·73	—	—

The Brinell values vary with the load applied, particularly in the case of the hard-drawn sample; and the ratio between the values for the two samples varies even more widely. Although the values marked by asterisks may be left out of consideration, in view of the perceptible bulging of the ⅝-inch bar under the heavier loads, the drawn metal may be anything from 110 to 75 per cent harder than the annealed.

In the above Table, the Brinell hardness values—expressed in $\frac{\text{tons}}{\text{in.}^2}$ instead of the more customary $\frac{\text{kg.}}{\text{mm.}^2}$—have been computed by the standard method, dividing the load by the contact area of the spherical indentation, $A = \frac{\pi}{2} D\left(D - \sqrt{D^2 - d^2}\right)$. Alternatively, a modified Brinell value may be computed by dividing the load by the projected area of the indentation, $A^1 = \frac{\pi}{4} d^2$. On the latter basis, the values are somewhat greater, as follow :—

Load. Tons.	½	1	1½	2	2½	3	3½	4
CH" (D) $\frac{\text{tons}}{\text{in.}^2}$	56·3	57·0	—	57·3	56.6	55·6	53·2*	52·2*
CH" (A) $\frac{\text{tons}}{\text{in.}^2}$	27·6	30·6	33·1	34·1	35·5	36·1*	—	—
Ratio $\frac{(D)}{(A)}$	2·04	1·86	—	1·68	1·60	1·54	—	—

The ratio between the values for the two samples varies at least

as widely as before; but the variation arises, chiefly, from the figure for the annealed sample. It appears that neither method of calculating the Brinell hardness gives consistent results in both samples.

The Brinell graphs, BH (D) and BH (A), plotted in Fig. 12, indicate maxima of 55·5 and 29·6 tons per sq. inch, respectively 1·75 and 1·85 times as great as the values obtained by the prism method. The ratio between the Brinell maxima, 1·88, may be regarded, probably, as the figure that is most comparable with the 1.96 hardness ratio indicated by the prism tests. Brinell tests with the larger and smaller standard loads of 3,000 and 500 kg. indicate hardness ratios of 2·09 and 1·73 respectively.

Effect of Change in Prism Angle.—Prior to an investigation on the point, it was anticipated that the results of prism-hardness tests would vary widely with the angle of the prism; but experiment shows that minor changes in the prism angle hardly affect the numerical value of the ratio $\frac{P}{x^2}$ where x is the width of the indentation, measured from corner to corner along the cutting edge.

Experiments were carried out on samples of the hard-drawn copper used in the foregoing tests. Pairs of test-pieces were cut to different angles from 60° to 150°, and tested with loads of 1 and 2 tons. The hardness values, $\frac{P}{x^2}$, obtained in this series are as follow:—

Prism-angle	60	86	90	94	120	150
$\frac{P}{x^2}$ tons in.$^{-2}$	32·6	31·5	31·4	30·5	30·4	30·3

The variation is too slight, in comparison with unavoidable experimental variance, to deduce any empirical relation; but the total variation between 60° and 150° is only 7 per cent—less than $\frac{1}{10}$ per cent per degree. Had the depth of the indentation been used, instead of the width, as the characteristic linear dimension x, the results would have varied widely because the depth of indentation is much greater with the sharper angles. Figs. 13 and 14, Plate 13, illustrate the contrast between the indentations obtained with 60° and 120°.

Further experiments were carried out on a pair of prisms having unequal angles, namely, 86° and 94° :—

Load P	For the 86° prism.		For the 94° prism.		Mean.
Tons.	x in.	$\frac{P}{x^2}$	x in.	$\frac{P}{x^2}$	$\frac{P}{x^2}$
1	0·186	28·9	0·176	32·3	30·6
2	0·267	28·1	0·248	32·6	30·3

The mean of the two means, 30·45 $\frac{\text{tons}}{\text{in.}^2}$, is approximately 3 per cent less than the mean of the three values obtained with the 86°, 90° and 94° pairs. The discrepancy is attributed, in part, to the slightly lower hardness (30·5) of the 94° sample. In other tests, in which the two prisms have differed slightly in hardness, the results have likewise approximated to the true value for the softer of the two samples.

It is inferred that variations in the prism-angle, within the limits of ordinary workmanship, have little influence on the results of the prism-test. The prism-angle may be varied even widely without producing any important change in the hardness value. The values may, therefore, be termed " prism-hardness "—in distinction from ball- or cone-hardnesses—without reference to the prism-angle.

In order to avoid splintering brittle materials—whether hard or soft—it may be advisable, occasionally, to use prism-angles greater than 90°. The right-angle, however, is doubtless more convenient as a general standard, more particularly as the broken ends of Izod impact test-pieces, machined to 90°, are commonly at hand.

Tests on Copper Alloys.—Series of tests were carried out on naval-brass (60–39–1) and Delta metals, I, II, and IV, supplied in square or round bars from which ½-inch square prisms were cut. The samples were not annealed or otherwise heat-treated. The results of prism-hardness tests with different loads are as follows :—

Load.	Tons.	1	2	3	4	5
Naval-brass.	$\frac{\text{tons}}{\text{in.}^2}$	36·5	35·8	35·3	34·8	33·5
Delta I	,,	60·3	61·4	59·6	57·7	58·0
,, II	,,	60·9	59·8	57·9	56·3	—
,, IV	,,	43·6	44 2	43·4	42·4	41·8

The naval-brass, which was of good commercial quality (ultimate tensile 26·8 tons/in.², 25½ per cent elongation on 6¾ diameters, yield point about 11 tons/in.²) gave peculiarly variable results in Brinell tests, as follows :—

Load, lb. (10 mm. ball)	200	400	600	1,000	2,000	3,000	4,000	5,000	6,000.
Brinell, $\frac{\text{kg.}}{\text{mm.}^2}$	63	64	78	79	89	87	90·5	92	93.

Taking the probable value for the standard 3,000 kg. load as 93 kg./mm.² = 59·2 tons/in.², and the probable prism-hardness as 36·5 tons/in.², the ratio between the hardness values is 1·62.

Except in the case of Delta II, which proved somewhat brittle, no difficulty was experienced in testing any of these alloys by the prism method. In Delta II, the corners of the indentation showed a tendency to split away under heavy loads, and it was not, therefore, practicable to apply the full load of 5 tons on the ½-inch prism. No difficulty of this sort was experienced in the Brinell test, which gave comparatively consistent figures in the case of Delta II, namely :—

Load in kg., 10 mm. ball	500	1,000	1,500	2,000	2,500	3,000
Brinell, $\frac{\text{kg.}}{\text{mm.}^2}$	140	145	150	152	154	153

Comparing the Brinell value for 3,000 kg., namely, $\frac{153 \text{ kg.}}{\text{mm}^2} = \frac{97{\cdot}3 \text{ tons}}{\text{in.}^2}$ with the prism value 60·5, the ratio between the two is found to be 1·61.

Tests on Pearlitic Steels.—Four series of tests were made on a forged steel containing about 0·18 per cent carbon. The different series correspond to different heat-treatments, namely, (1) material tested as forged ; (2) after quenching in water from 890° C. ; (3) quenched in water from 890° C. and tempered for 30 minutes at 300° C. ; (4) treated as 3 but finally quenched in oil from 800° C. The results obtained are as follows :—

Load.	Tons.	½	1	2	3	4	5
PH (1)	$\frac{\text{tons}}{\text{in.}^2}$	49·2	49·7	50·0	50·6	49·2	48·8
PH (2)	,,	—	80·5	80·5	84·0	70·0	70·0
PH (3)	,,	—	63·2	60·7	61·3	63·9	63·4
PH (4)	,,	—	58·8	58·0	56·9	58·1	58·0

The irregular figures obtained in the second (quenched) set are attributed to the condition of the steel.

The above results may be compared with Brinell tests carried out with the standard load of 3,000 kg. on a 10 mm. ball.

Sample Number	(1)	(2)	(3)	(4)
PH (as above)	49·6	70 80	62·5	58·0
Brinell $\frac{\text{kg.}}{\text{mm.}^2}$	135	200	170	155
BH $\frac{\text{tons}}{\text{in.}^2}$	85·8	127	108	98·5
Ratio $\frac{(\text{BH})}{(\text{PH})}$	1·73	1·8–1·5	1·73	1·70

When the two hardness values are expressed in the same units, tons/in.^{2}, the Brinell value is 70–75 per cent greater than the prism-hardness value.

Another sample of mild-steel, giving a tensile of 31 $\frac{\text{tons}}{\text{in.}^2}$ ultimate, gave similar prism-hardness values, namely :—

Load.	Tons.	1	2	3	4	5
PH	$\frac{\text{tons}}{\text{in.}^2}$	54·8	53·3	52·9	52·0	51·2

The gradual fall of hardness with increasing load, in this instance, is attributed to irregular structure caused by rolling at moderate temperature. The steel, which had been rolled to a $\frac{1}{2}$-inch square bar, showed the masked yield-point which, in a tensile test, characterizes cold working. It is probable that the corners of the bar were harder than the underlying metal.

Four samples of a harder steel, containing 0·43 per cent C., were also tested after different heat-treatments (1) as forged ; (2) forged and quenched in water from 850° C. ; (3) treated as 2 and then tempered for 30 minutes at 300° C. ; (4) treated as 3 and finally quenched in oil from 750° C. The results may be summarized as follows :

Sample	(1)	(2)	(3)	(4)
PH $\frac{\text{tons}}{\text{in.}^2}$	70·2	189	102	81·2
BH „	117·5	380	216	127
Ratio $\frac{(\text{BH})}{(\text{PH})}$	1·67	2·0	2·1	1·56

A bar of Bessemer steel was tested before and after being strained in direct tension, with 8½ per cent elongation, giving two sets of values as follows :—

Load.	Tons.	1		3	4	5
PH (before)	$\frac{\text{tons}}{\text{in.}^2}$	75·7	75·8	75·3	75·4	75·7
PH (after)	,,	85·7	83·7	84·2	84·3	84·1

The increase of hardness, due to straining, is approximately 12 per cent. In a tensile test, the steel showed a yield-point of 40·5 tons/in.² and extended 8½ per cent when the load was increased by 19 per cent. The ultimate strength was 53·8 tons/in.², and the elongation at fracture 15·2 per cent with 50·5 per cent reduction of area.

Samples of "Spring-steel" and "Silver-steel" gave results nearly alike as follows :—

Load.	Tons.	1	2	3	4	5
PH (spring)	$\frac{\text{tons}}{\text{in.}^2}$	75·2	78·5	78·6	79·7	79·5
PH (silver)	,,	78·3	79·8	80·4	81·2	—

In these samples, the gradual increase of hardness with load is attributed to difference of composition. Transverse sections, under the microscope, showed that the carbon percentage was distinctly lower at the corners than in the middle of the bars.

Two high-carbon tool steels, containing 1¼ and 1½ per cent carbon, were tested in ½-inch square bars, as received, without heat-treatment. The results were nearly alike, namely :—

Load.	Tons.	1	2	3	4	5
PH (1¼ per cent C.)	$\frac{\text{tons}}{\text{in.}^2}$	102·0	107·0	107·2	102·0	103·1
PH (1½ per cent C.)	,,	103·0	105·0	100·2	100·7	100·2

Brinell tests with 3,000 kg. on 10 mm. ball indicated 286 and 277 kg./mm.² respectively. The ratios between the Brinell and prism values, expressed in the same units are, therefore, 1·70 and 1·79 respectively. Under 2,000 kg., the Brinell values were alike, namely, 258, corresponding to ratios of 1·61 and 1·58. In carbon steels, the value of the ratio appears to run from 1·60 to 1·80 in different samples.

The foregoing experiments indicate that the prism-hardness of pearlitic carbon-steel increases from about 50 with 0·18 per cent carbon to 100 tons/in.^{2} with 0·9 per cent, and thereafter remains approximately constant; but the value varies, naturally, with the heat treatment as well as the carbon percentage.

Test on Austenitic Manganese Steel.—A sample of "Era" manganese steel, tested by the prism and Brinell methods, gave the following figures :—

Load.	Tons.	1	2	3	4	5
PH	tons in.^{2}	71·8	71·4	70·2	68·8	68·7
BH		107	119	120	122	125

Although the prism hardness of "Era" is thus no greater than that of a normalized 0·7 per cent carbon steel, the form of the indentation is markedly different, resembling that of annealed copper. Only in this respect does the hardness test give any evidence of the remarkable quality that the metal possesses, namely, abnormal hardening with overstrain. The gradual fall in prism-hardness with increase of load is attributed to the small size of the test-piece and to the comparatively wide-spread displacement that occurs in this metal. Taking the probable hardness values, PH and BH, as 71·8 and 120 tons/in.^{2}, the ratio between the two is 1·67—approximately the same as in Pearlitic steel.

Tests on Martensitic Steels.—Prior to a number of tests on high-carbon and alloyed steels of great hardness, it had been anticipated that Martensitic steels might splinter in the prism test, without forming regular indentations. Experiment showed, however, that even the hardest carbon-steels can be indented by the prism method, with 90° angle; and that splintering occurs only in brittle samples when the load exceeds a value that is amply sufficient to yield a measurable indentation. The form of the indentation, in Martensitic steel, resembles that obtained in hard-drawn copper, but is even more local.

Three series of tests were made on a high-carbon alloy steel, as used in the bearing balls employed in making Brinell tests. The three samples had received different heat-treatments, namely,

(1) normalized, as delivered ; (2) heated to 800° C. for 15 minutes and quenched in water ; (3) treated as (2) and tempered at 390° F. for 10 minutes. The results obtained in prism tests were as follows :—

Load.	Tons.	1	2	3	4	5	Mean.
PH (1)	tons in.$^{-2}$	76·2	74·5	75·4	74·9	72·5	74·7
PH (2)	,,	314	310	323	316	326	318
PH (3)	,,	265	276	276	259	266	268

It is evident that tempering, even at the moderate temperature of 200° C., has resulted in 16 per cent loss of hardness. It is interesting to note, also, that the maximum hardness of this alloy steel is some 18 per cent less than that observed in subsequent tests on simple carbon steels.

Similar results were obtained in tests on other alloyed steels, hardened and tempered at different temperatures, giving prism-hardness values from 325 to 240 tons/in.^{2}

Four knife-edges, in the form of $\frac{1}{2}$-inch square bars, afford an example of the hardness attainable in carbon steel. The four bars had been hardened on different dates, in works practice, and were untempered. Two had been rejected, namely, sample C for brittleness, and sample D for water cracks. Prism tests gave the following hardness values :—

Load.	Prism Hardness. $\frac{\text{tons}}{\text{in.}^2}$			
Tons. Sample . .	A	B	C	D
$\frac{1}{4}$	—	—	359	388
$\frac{1}{2}$	282	403	357	358
$\frac{3}{4}$	288	—	354	—
1	298	392	359	376
$1\frac{1}{4}$	293	—	345	—
$1\frac{1}{2}$	289	382	*	393
$1\frac{3}{4}$	—	—	—	387
2	294	380	—	*
3	287	373		
4	283	378		
5	287	387		
Means	286	385	355	380

Samples B, C and D appear to be fully hardened, while A is

decidedly softer. The hardness values do not vary with load more widely than may be attributed to experimental variance or slight changes of structure, and may be regarded as independent of the load applied in making the test. Although A and B gave consistent values and regular indentations with all loads up to the maximum of 5 tons, samples C and D invariably splintered when the load reached a certain limit which, in each sample, was fairly definite as marked by asterisk in the Table. Splintering occurred under lower loads applied jerkily.

This evidence of brittleness, although it limits the load that can be applied in making the test, is probably a serviceable feature. Thus the foregoing tests show that sample B is not merely as hard as or harder than D but much tougher. As compared with B—which is the hardest metal yet tested by the Author—sample C is lacking alike in hardness and toughness.

In the foregoing samples, splintering occurred locally, chips flying from the edges of the indentation, which then collapsed. In other cases, test-pieces cracked transversly when the load reached a limiting value. This occurred in a sample of $1\frac{1}{2}$ per cent carbon steel, hardened by quenching in cold water. Under loads of 2 and 3 tons, this brittle specimen gave consistent prism-hardness values of 350 tons/in.^{2}; but at $3\frac{1}{2}$ tons the test-pieces snapped. The limiting load does not appear to depend on the sharpness of the angle, but rather, on the transverse dimensions of the test-piece.

Up to the present, no tests have been made at temperatures other than 60–75° F., but apparatus is in hand for testing samples up to red-heat. It is anticipated that prism-hardness tests on high-speed steels will yield figures indicating a gradual, or eventually more rapid fall in hardness with increasing temperature; and that comparisons between different steels should prove serviceable as a guide to the permissible working temperatures. Although hardness tests on such steels, at air temperature, are of little practical value, it may be of interest to note that one sample, tested cold under 5 tons applied near the working edge, showed a prism-hardness of 277 tons/in.^{2}.

It is considered that the crossed-prism hardness test should be

of service in many fields of research. The consistent results and convenience of the method are evident; and, in the Author's experience, the test has proved sensitive to slight differences of hardness, even in the hardest metals. As one and the same scale—a scale of stress—is equally applicable for the hardest and softest metals, the prism test should prove serviceable as a reference standard.

The experiments described were carried out in the engineering laboratories of the Royal Naval College, Greenwich, under the charge of Professor J. B. Henderson, D.Sc.; the Author is indebted, also, to Sir Robert Hadfield, Bart., Messsr. W. and T. Avery and Co., Ltd., Messrs. H. S. and J. S. Glen Primrose, and others, who have kindly supplied materials with different heat-treatments, selected with a view to ascertaining the capabilities of the test.

The Paper is illustrated by Plates 12 and 13 and 6 Figs. in the letterpress.

THE MEASUREMENT OF HIGH DEGREES OF HARDNESS.*

By JOHN INNES, of Whitley Bay, Northumberland.

[*Selected for Publication, and abridged*].

The Definition and Measurement of Hardness.—The earliest writer to attach a precise meaning to the term "hardness" was Heinrich Rudolf Hertz, and in forty years no one has challenged the soundness of his reasoning or disputed the paramount importance of the mechanical property to which it relates. The object of this Paper is to show that if a certain presumption relating to the strength of materials be admitted, then hardness as defined by Hertz can be measured without much difficulty, and probably at less expense when the material is very hard than when it is only moderately hard. The criterion of hardness which has been adopted is not that chosen by Hertz, but the method proposed is not restricted to any particular criterion.

It should be clearly understood that whatever may be of value in the Paper is due to Hertz, Lord Kelvin, Sir George Darwin and others; the compiler is responsible for the trivialities and errors.

Hertz's conception of hardness relates only to bodies which are homogeneous and isotropic. The elastic properties of such materials can be expressed in two terms which will be written:—

"K." The modulus for change of size. [1, 3, 4.] †

"C." The modulus for change of shape.

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* Awarded a Prize of £7 by the Sir Robert Hadfield Prize Committee.

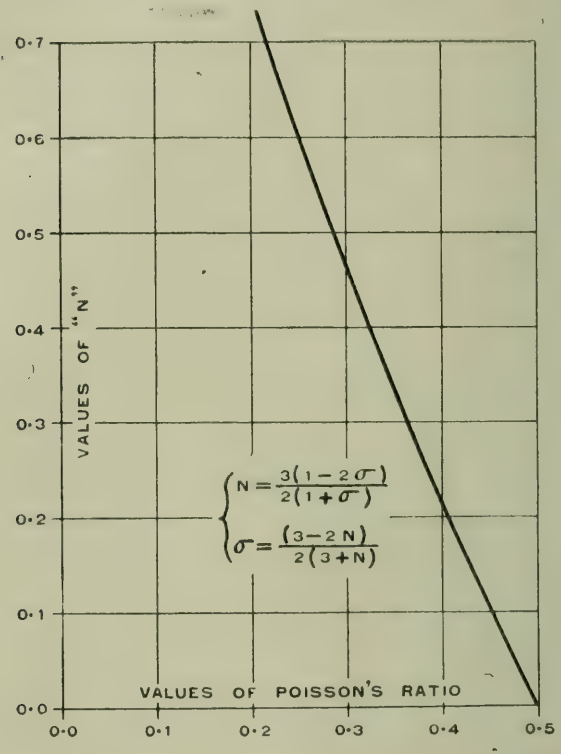
† Figures in square brackets refer to Authorities mentioned in the Appendix (page 932).

It will be convenient to use a symbol for the ratio of these constants, namely :—

$$\text{“N”} = \frac{C}{K}.$$

Poisson's ratio “σ” represents the same thing in a rather

FIG. 1.—*Poisson's Ratio and Ratio of Elastic Constants.*



unfortunate way, but is generally used instead of “N.” A conversion diagram is, therefore, given in Fig. 1.

“Homogeneous” materials owe the great variety of their statical characteristics to combinations in different degree of a comparatively small number of fundamental properties. [10, 11.] These are :—

(1) Density.
(2) The absolute values (possibly zero) of C and K.
(3) The strain range (possibly zero) for shear, condensation and dilatation in which the material is uniformly elastic. [5].
(4) The further strain range (possibly zero) in which the material is coherent. [12, 13, 15].
(5) The little known stress-strain relation in this last range.

If relative motion of the parts at finite velocities is to be considered, the question becomes much more complex. There appears, for example, to be a limit to the shearing velocity, as well as to the shear itself, beyond which the material fails to transmit shear stress.

The mathematical theory of statical elasticity applies only within the range referred to at (3) above, and then only if the strains dealt with are so small that their squares and products may be neglected. The dynamical theory is somewhat incomplete, but is a good guide in predictions of dynamical behaviour. Both theories are infinitely in advance of our experimental knowledge of the materials we have to deal in.

Hard-drawn copper-wire is stiff and springy, but by purely thermal treatment it may be made limp enough to serve as a substitute for string, or so brittle that it becomes difficult to handle without breakage. It is thus very evident that the name of a metal is far from being a complete specification of elastic and other mechanical qualities. Tables of K, C and related numbers and moduli may be found in Landolt-Börnstein's "Tabellen," the "Encyclopædia Britannica" and elsewhere; their striking feature is the wide range of values given for what is nominally the same material. Kelvin's experiments [8] on copper wires show that "N" may range from about 0·1 to seven times this quantity. Guest gives figures ranging from 0·15 to 0·50 for different grades of steel tubing all presumably "mild." These numbers result from a fortuitous selection of specimens and do not represent a systematic attempt to find the extreme range of variation or the influence of manufacturing methods on the product. It is a little surprising

that so real and fundamental a quality as "N" should have been almost completely neglected.

The constant "C" is better known, but varies considerably, and Kelvin gives figures differing by 20 per cent. for copper. Young's modulus for American open-hearth rivet steel appears to have a very similar range of values. [7.]

Knowledge of the limits of elasticity in metals is imperfect. Grossly heterogeneous materials like cast-iron cannot be expected to be very elastic. Certain forms of lead and copper [22], although apparently homogeneous, are uniformly elastic within a range which is extremely narrow, and possibly inappreciable.

It will be found that an element in the specification of hardness is the specification of the shear elastic limit. This is not an insuperable difficulty and it is a difficulty which must be faced. A corresponding, but more serious, embarrassment is to be found in any definition of "indentation hardness," where it becomes necessary to specify both the geometry and the degree of a plastic deformation. Engineers are accustomed to placing different interpretations on the term "elastic limit" according to the circumstances in which the material is to be used, e.g., whether it is to bear a momentary [16] or a continuous load and whether it is to be loaded once, or repeatedly; there is no alternative to placing a corresponding interpretation on the word "hardness."

Hertz's theory of hardness may be introduced by considering two rounded elastic bodies which just touch one another. When these are pressed together a dimple forms in each, and the original point of contact swells to a small but definite area. Generally this is elliptical, but in certain cases the ellipse may narrow to a line or broaden into a circle. The latter event clearly occurs when both bodies are spherical, or when one is spherical and the other flat. By a remarkable analysis Hertz found expressions for the stresses and strains at all points in two such bodies. The formulæ are the basis of his theory of hardness and become specially simple when the area of contact (called the pressure area) is circular.

Suppose that the bodies I and II, Fig. 2, of different materials, are pressed together by a force p acting along the common normal

at the original point of contact [14]. Fig. 3 shows, on a larger scale, the conditions near this point. The curvatures in and perpendicular to the plane of the diagram are here taken as being the same, viz., $\rho_1 = \frac{1}{R_1}$ and $\rho_2 = \frac{1}{R_2}$ where R_1 and R_2 are the radii of the bodies.

The pressure area in plan is a circle of radius a, and in section it lies between the original surfaces as shown. The "penetrations," relative to the distant parts of the bodies, are denoted by α_1 and α_2. Strictly speaking, a part is due to strains throughout the whole of the bodies, but the lines marked α_1 and α_2

Fig. 2.

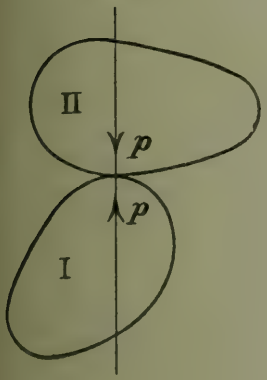
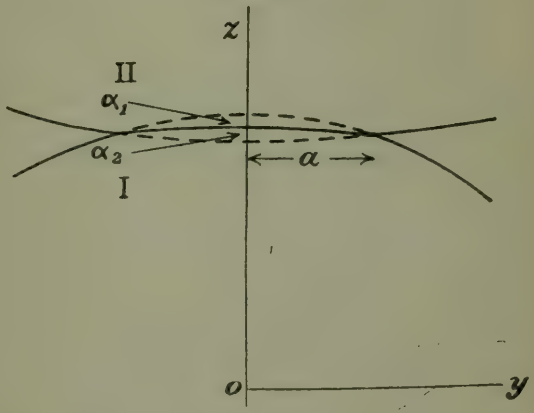


Fig. 3.



include the greater part of these "penetrations." Axes of y and z are taken as indicated. The x axis is perpendicular to the plane of the paper, and the origin, for body I, is fixed relative to the distant parts of I. The whole thing is symmetrical about the z axis, so the co-ordinates of a point are given by values of z and r where r is the distance from $o\,z$.

The symbol "I" represents a function of the elastic constants of the bodies given by:—

$$I_1 = \frac{(3 + 4\,N_1)}{C_1\,(3 + N_1)}, \quad I_2 = \frac{(3 + 4\,N_2)}{C_2\,(3 + N_2)}.$$

The principal geometrical formulæ are :—

$$a = \left[\frac{3\,p}{16}\,\frac{(I_1 + I_2)}{(\rho_1 + \rho_2)}\right]^{\frac{1}{3}}$$

$$a_1 = \frac{3\,p}{16a}\,I_1$$

$$a_2 = \frac{3\,p}{16a}\,I_2.$$

The surface of each body and the radial and tangential planes are principal planes of stress for points in the surface, which is the zone of highest stresses. Denoting these principal stresses in the surface by X, Y, and Z and the condensation by Δ, with suffices for special values of the radius, and for brevity writing :—

$$p^1 = \frac{3\,p}{2\,\pi\,a^2}$$

the stress system inside the pressure area is given by :—

$$X_2 = p^1 \left\{ \frac{N}{3+N}\,\frac{a^2}{2_2}\left[1 - \left(\frac{1}{a}\sqrt{a^2 - 2^2}\right)^3\right] + \frac{3 - 2N}{3+N}\,\frac{\sqrt{a^2 - 2^2}}{a} \right\}$$

$$Y_2 = -p^1 \left\{ \frac{N}{3+N}\,\frac{a^2}{2^2}\left[1 - \left(\frac{1}{a}\sqrt{a^2 - 2^2}\right)^3\right] - \frac{1}{a}\sqrt{a^2 - 2^2} \right\}$$

$$Z_2 = p^1 \left\{ \frac{\sqrt{a^2 - 2^2}}{a} \right\}$$

$$\Delta_2 = -p^1\,\frac{3N}{3+N}\,\frac{1}{c}\,\frac{\sqrt{a^2 - 2^2}}{a}$$

Outside the pressure area these simplify to :—

$$X_2 = p^1\,\frac{N}{3+N}\,\frac{a^2}{2^2}$$

$$Y_2 = -X_2$$

$$Z_2 = 0$$

$$\Delta_2 = 0.$$

At the centre :—

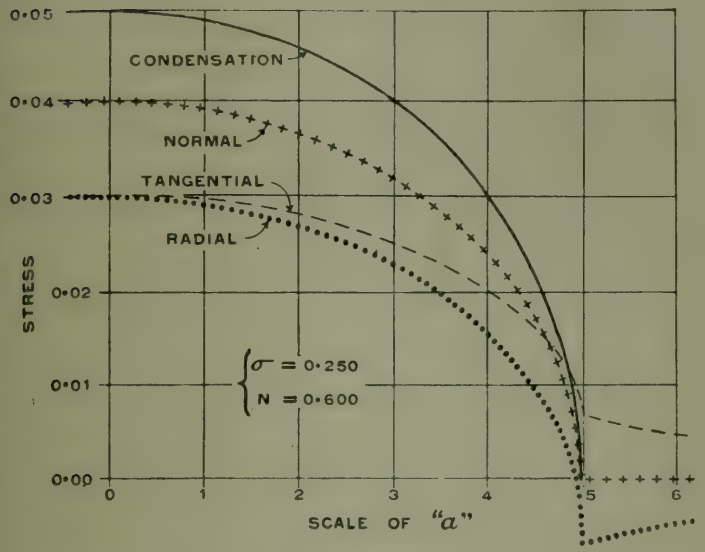
$$X_0 = p^1\,\frac{(6 - N)}{2\,(3+N)}$$

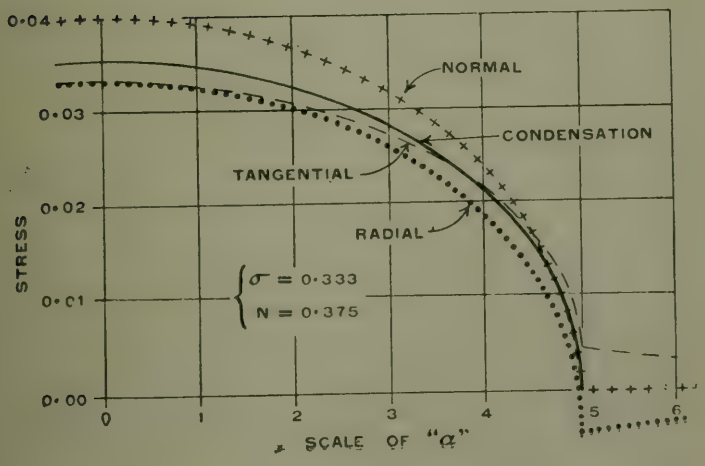
$$Y_0 = X_0$$

$$Z_0 = p^1$$

$$\Delta_0 = -p^1\,\frac{3N}{2+N}\,\frac{1}{c}.$$

FIGS. 4 AND 5.—*Surface Stresses in terms of* $\frac{3p}{2\pi}$.
Condensation $\left(\text{in terms of } \frac{3p}{2\pi E}\right)$.



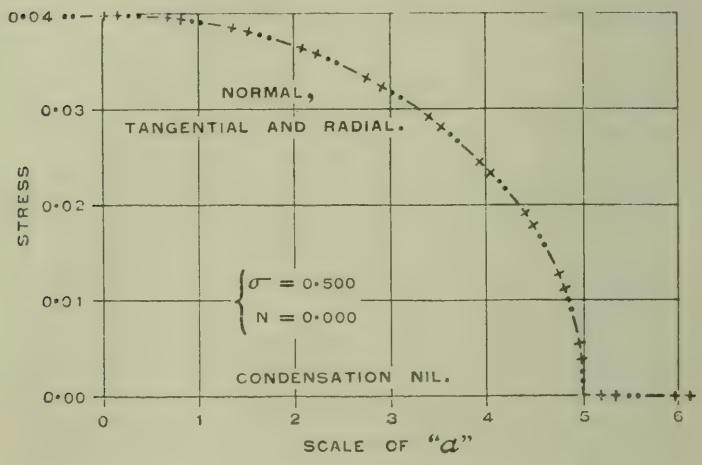


And at the edge of the pressure area:—

$$Xa = p^1 \frac{N}{3+N}$$
$$Ya = -Xa$$
$$Za = 0$$
$$\Delta a = 0.$$

The general distribution of surface stress is shown in Figs. 4, 5, and 6, for three typical values of "N." For the sake of ready comparison the radii of the pressure surface are made the same, and the total pressures therefore differ in each of the three diagrams,

Fig. 6.—*Surface Stresses in terms of* $\frac{3p}{2\pi}$.



whose ordinates represent the stresses in terms of $\frac{3p}{2\pi}$, where p in each case is the total pressure.

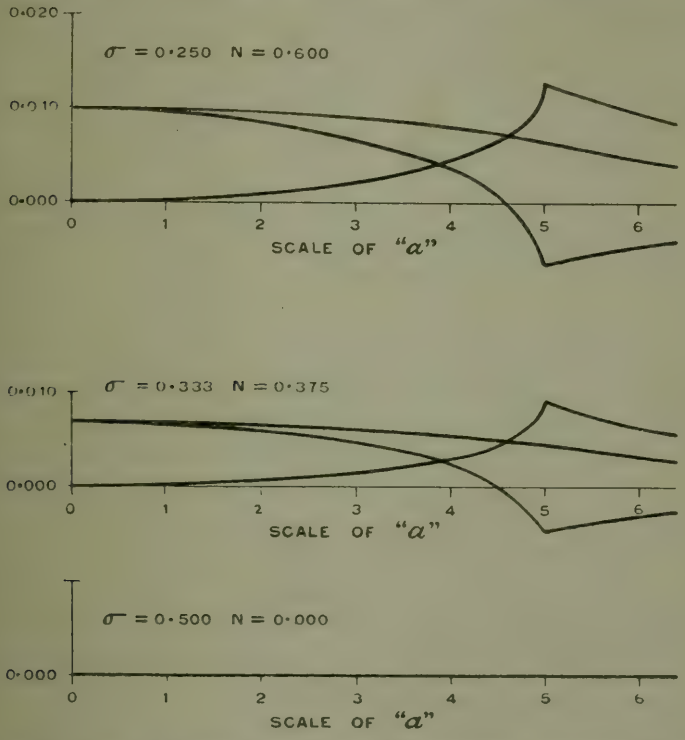
In the last diagram ($N=0$) p must be zero as with $N=0$ a body can stand no local surface pressure.

The whole problem of the (elastic) strength of materials may be stated very simply [9]. A cube is subject to pressures (positive or negative) X Y Z on opposite pairs of faces, and it is required to establish the limits within which X Y Z must lie to be consistent with linear elasticity.

Consideration of the way in which things break, points to the existence of two alternative criteria [11], excessive shear and excessive dilatation, but opinion seems to be divided as regards the latter [8, 17]. It is admitted that dilatation may influence the shear limit, but experiment shows this effect to be comparatively small.

The force system X Y Z on the cube may be regarded as the

FIGS. 7, 8 AND 9.—*Stress Differences at varying radii for three Values of "N."*



average " W " of these forces, acting inwards or outwards as the case may be, together with the individual differences from the mean $x\ y\ z$ say, acting inwards or outwards according to their sign. The sum $x\ y\ z$ is then necessarily zero; " W " is called the mean tension and results in dilatation or compression while $x\ y$ and z produce change of shape.

It is known that the density of metals can be altered by strain; permanent increases having been recorded, for instance, by Kelvin [8] and permanent decreases by Styffe. [6] It seems probable that these changes are due to "residual" shear strain and are not to be regarded as evidence of the imperfection of volume elasticity [23]. As an example, those who are familiar with the effect of capped shell on armour plates will agree that pressures of some hundreds of tons per square inch do not alter the density of hardened steel appreciably. It does not follow, of course, that the modulus K remains invariable; the recorded values, in fact, relate to very moderate stresses, and there are reasons for supposing that the range of pressure within which K is constant is a fairly narrow one.

As a working hypothesis, however, it is assumed that, at any rate for the harder metals, the elasticity of volume compression is perfect and uniform, and that its limit, in indentation experiments, is not reached until after the material has first yielded by inelastic shear.

Figs. 7, 8, and 9 (corresponding to Figs. 4, 5 and 6) show the distribution of shear stress arising from circular pressure contact. At the centre there are two equal shears of considerable amount as well as a considerable condensation. In Lord Kelvin's opinion the condensation will help the material to resist shear [8, 3].

Inspection of the figures shows that, as we proceed from the centre of the pressure area to the circumference, the two shear stresses become smaller, and a third comes into being which gradually rises to a maximum at the edge of the pressure area. This is the greatest shear stress in the whole system. Inwards along the radius the stress falls rapidly, outwards it falls more slowly. Materials which are not exactly uniform may be expected to break either at the edge of the pressure area or slightly outside it. Ice, glass, flint, resin and hard steel behave in conformity with this expectation, and it may be confidently assumed that all materials having a high value of N (whatever their strength) will do likewise.

It has been proved by many experiments that ductile materials first fail at the point of greatest shear stress, and the observations

just quoted show that materials like glass and flint behave in the same way [17, 18, 19, 20]. The generalization of this rule, and the further supposition that, in the absence of condensation, breakage or flow is conditional on nothing but the value of the shear stress constitutes the presumption alluded to in the early part of the Paper.

When an indenting tool of radius R and elasticity I_τ is pressed against the plane surface (elasticity I,N) whose properties are to be investigated, it follows from Hertz' equations that:—

$$p = \frac{\pi^3}{96} \frac{(I_\tau + I)^2 (3 + N)^3}{N^3} R^2 q^3$$

where p is the total pressure and q is the shear stress at the edge of the pressure area.

Taking as the definition of hardness (H) the value of p which, with R as unity, makes q equal to the limiting shear stress ("Q") that the material can stand:—

$$H = \frac{\pi^3}{96} \frac{(I_\tau + I)^2 (3 + N)^3}{N^3} Q^3.$$

The equation shows very clearly how lack of rigidity in the tool complicates direct hardness measurement, and why, for steel of "Brinell hardness" 700, it is preferable to use a diamond ball of somewhat greater "hardness" rather than a steel one of "hardness" 100 [2].

It will be noticed that a simplification of the equation can be made if I_τ is either equal to, or considerably greater than I. Taking the latter case first, and supposing that the tool is ideally rigid, i.e., $I_\tau = 0$, and writing I in terms of N and C.

$$H = \frac{\pi^3}{96} \frac{(3 + 4N)^2 (3 + N)}{N^3} \frac{Q^3}{C^2}.$$

The conditions represented in this equation appear to be convenient as a definition of hardness, but if the conception of an ideally rigid body be regarded as illegitimate, it is only necessary to suppose the tool and surface made of the same material. The value of the hardness thus defined is four times as great as it would be under the "rigid tool" definition.

Fig. 10.

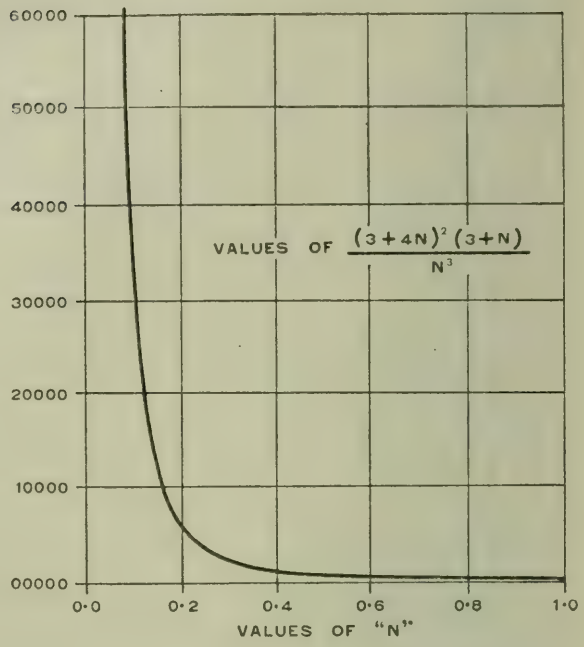
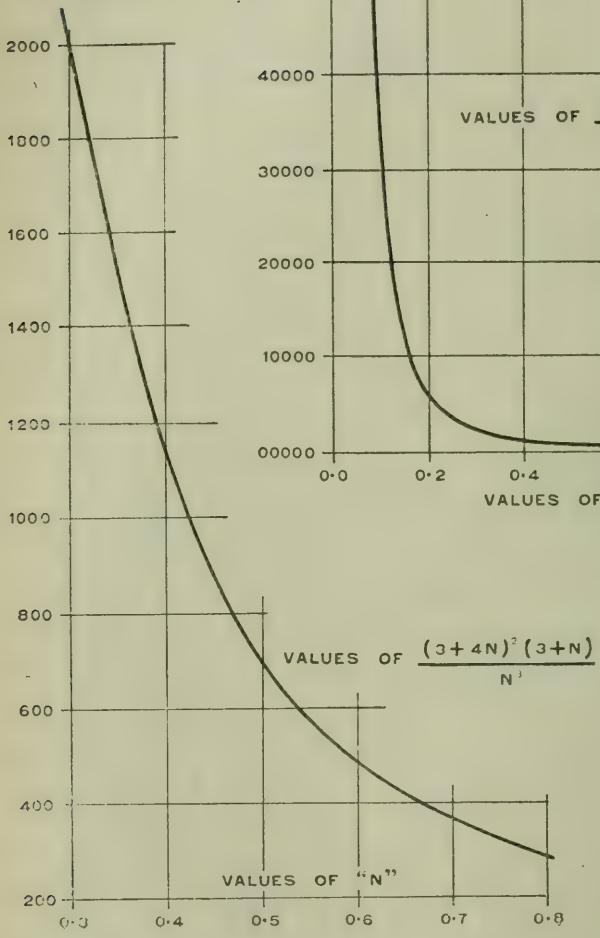

60000
50000
40000
30000
20000
10000
00000
VALUES OF $\frac{(3+4N)^2(3+N)}{N^3}$
0·0
0·2
0·4
0·6
0·8
1·0
VALUES OF "N"

Fig. 11.


2000
1800
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400
200
VALUES OF $\frac{(3+4N)^2(3+N)}{N^3}$
VALUES OF "N"
0·3
0·4
0·5
0·6
0·7
0·8

The function $\frac{(3+4N)^2}{N^3}\frac{(3+N)}{}$ is given in terms of N in Figs. 10 and 11.

The established methods of determining hardness directly involve only very small masses of the material concerned. Within these small masses, the stresses and strains vary steeply from point to point, and only reach their limiting value in zones of still smaller order. When applied to heterogeneous metals these methods are somewhat unsatisfactory, and a procedure involving a comparatively large bulk of such materials is in many ways to be preferred.

The equation which has just been given for "H" in terms of N, C, and Q provides a means of measuring hardness, as each of the three factors can readily be determined separately.

If test-pieces of moderate size (e.g., rods of $\frac{1}{10}$ inch diameter and 3 inches long) are available, two of the constants (C and N) in the equation for hardness may be measured with almost any desired degree of accuracy.

The trifling difficulty of defining the shear elastic limit has already been referred to. It will probably prove necessary to specify the size of the test-piece, the rate of loading and the degree of non-proportionality between stress and strain. These are simple matters calling for a mere decision, and the hardness value found for a surface will correspond strictly to the particular decision taken.

The modulus "C" may be measured with high accuracy by observing the angle through which a cylindrical specimen twists under a known torque, and a convenient optical instrument has been described by Guest in the "Philosophical Magazine" for 1900. The same apparatus, of course, will serve for the measurement of "Q," but for the reasons given by Guest it is necessary to use thin tubular specimens when the material is a "ductile" one.

There are but few recorded measurements of "Q" for "brittle" materials and for these, solid specimens may give satisfactory results, especially if the measuring arrangements are autographic, and the stress is rapidly and steadily increased to the breaking point without jolts and pauses. This can be arranged by using as load a vessel into which water or lead shot may be poured.

As a practical point of some importance, the employment of large specimens and huge machines for hardness testing is to be deprecated. The errors in such operations are often considerable, and half a dozen experiments on pieces of say $\frac{1}{10}$ inch diameter are both cheaper and more likely to give a representative result than a single experiment on a larger piece. Single experiments are apt to be misleading, as they must always leave undiscovered the variability of the material and possible erratic working of the testing machine.

The bulk modulus "K" [21] has been measured directly, but large specimens are required to ensure even moderate accuracy. Alternatively, "K" may be computed from "C" and one of the composite moduli, say Young's modulus, or by direct observation of the ratio of lateral contraction to longitudinal extension in a rod under tension. A description of an appliance for measuring lateral contraction in a circular rod of comparatively small diameter follows. The principle of the apparatus is that of the taximeter, where the counted revolutions of a rolling wheel measure the distance run.

Fig. 12 represents a "carrier" intended to rotate around the test-piece without "play" and without much friction. It has a hinged door provided with a catch and runs on six internal rollers, four of which have bearings fixed in the main part of the carrier. The other two rollers have their bearings in radial slides attached to the door, the slides being pressed inwards by springs so that when the door is shut the whole carrier cannot wobble. The carrier has an external groove for a driving band, and its axial position on the test-piece is controlled by a fork on independent supports.

Fig. 13 shows a swing gate hinged internally to the carrier. The gate carries the bearings of the recording wheel and has an adjustable spring (not shown) by means of which the pressure between the wheel and specimen may be varied at will and estimated by observing the position of the adjusting screw. The gate has balance weights so disposed that central acceleration due to rotation does not much affect this pressure.

Fig. 14 shows the top of the instrument in diagrammatic plan.

Fig. 12.

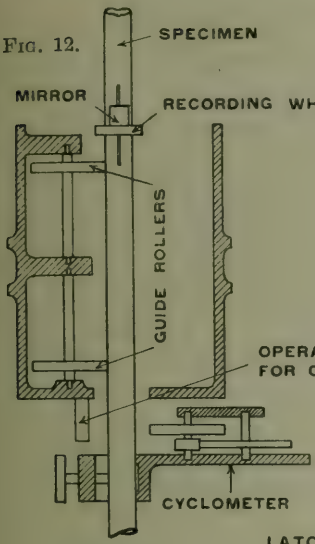
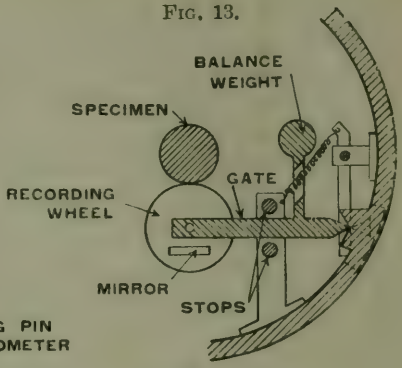
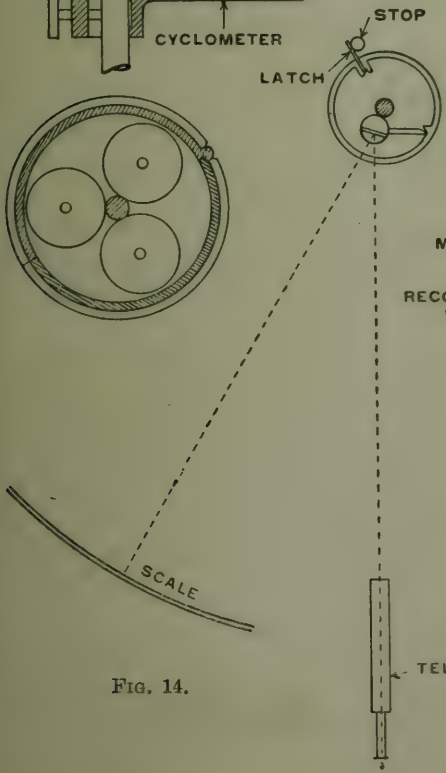


Fig. 13.





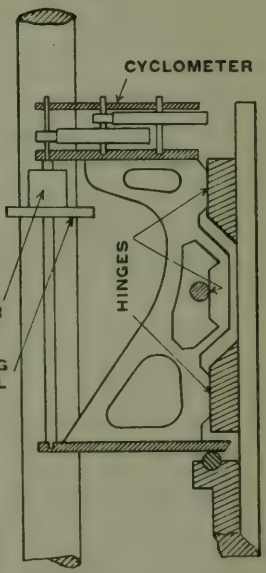


Fig. 14.

To fix the initial and final positions of the carrier accurately, a ball stop is fixed to the upper part of the test-piece. A latch in the carrier is capable of taking two positions, an outward one in which it engages the ball, and an inward one in which these parts run clear. The recording wheel carries a vertical mirror and its angular position is measured by the reflection of a concentric scale. Its complete revolutions relative to the gate, as well as the revolutions of the carrier, are indicated by counting wheels.

Measurement of the lengthwise extension of the specimen is first made under varying loads with any of the well-known "extensometers," for instance Ewing's. The rolling instrument and stop are then placed in position and the former turned by hand until, with the stop just engaged, the mirror is in a position which permits a scale reading. The stop is then disengaged and the instrument run for some thousands of revolutions by motor. A further rotation by hand enables a final scale reading to be obtained with the stop engaged. The difference of scale readings, with the indications of the counting wheels, affords a measure of the diameter of the specimen, and such measurements may be made under various tensions.

By altering the pressure between the recording wheel and specimen, the influence of elastic compression at the point of contact may be estimated, and allowed for if it is found to be important.

The value of "N" is computed from the recorded ratio of the longitudinal and lateral strains under the same load. In most instruments it is convenient to make some of the parts adjustable by means of screws, but for the sake of clearness these details have been omitted from the figures. The minutiæ of construction depend so much on the precise circumstances in which the instrument is to be employed, that nothing but the essentials of mechanical arrangement are indicated.

Materials like jellies and indiarubber with a low shear modulus usually permit of considerable shear strain before rupture occurs. Glue jellies with decreasing water content ultimately become brittle. Soft copper with a low shear modulus has a wider angular

range of plasticity than hard varieties of the same metal, and a similar comparison may be made between the harder and softer varieties of carbon steel. In the writer's opinion the rule is a general one and it seems to follow that the hardest members of a class of materials like alloy steels will probably be "brittle," that is, of the kind that can propagate cracks and that break "short" under torsion without taking much "permanent set."

If the rule is a sound one the definition of hardness for the harder steels may possibly be simplified by taking the shear breaking stress as equivalent to the elastic limit of shear. When applied to a twisted rod, this is a somewhat different and more legitimate supposition than that made by Hertz [9] who adopted the rule in connexion with his determinations of the hardness of pieces of glass.

Experiment only can decide the point, but there is a possibility that solid test pieces and tubular ones will give parallel results when broken by torsion, and if they do so the cost of test pieces would be reduced.

The Paper is illustrated by 14 Figs. in the letterpress, and is accompanied by an Appendix.

[*For Appendix, see next page.*]

APPENDIX.

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HARDNESS TESTING.

(BY MEANS OF TWO NEW TYPES OF MACHINES.)

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[*Selected for Publication.*]

General Principle of Load Calibrating Box.—On a former occasion the Authors, in their Paper on "Some Useful Testing Machines," read before the West of Scotland Iron and Steel Institute and the South Staffordshire Iron and Steel Institute, described a new form of standardizing box for calibrating testing machines in tension or compression stresses. The principle of this instrument is that, when subjected to a tension or compression load, it is deformed in a degree proportional to the stress applied, and the volume change of the box gives a very accurate measurement of the load applied by means of a micrometer reading. The readings are also invariable for each box of the three different sizes made.

The standardizing boxes are constructed in the form of thin-walled, hollow cylinders made of special steel which has been suitably heat-treated, so that, even when highly stressed, they do not suffer any permanent deformation. The interior of the box is filled with mercury (A), Fig. 1, Plate 14, and the fullness of the cavity is indicated by the level of the column of mercury extending into the capillary glass tube (B), mounted in the side of the instrument. On this tube is a sliding mark (C) to which the level of the mercury column is always brought back by turning the micrometer-screw (D) which moves the plunger (E) projecting into the mercury-filled space, and thus causes the mercury column to move along the capillary tube.

When the hollow cylinder is stressed perfectly axially, its volume decreases under compression and increases in tension, and by reason of this an amount of mercury equal to the volume change is forced into or withdrawn from the capillary tube. In the first case the expelled mercury which cannot remain in the capillary tube collects in the bulb (F) at the end of the tube, until, by turning the micrometer-screw, the end of the mercury column is brought back to the edge of the datum mark. Although the walls (G) of the steel cylinder are thin in order to obtain large volume displacements of the mercury, which are thus readily observed, the box is so designed as not to be loaded above its elastic limit. It, therefore, shortens proportionately with the end loading and decreases in volume, consequently the amount by which the micrometer-screw has to be turned is also proportional to the load.

By reason of the fact that the micrometer reading is always got by returning the level of the mercury column to the zero mark, the number of turns given to the screw and the readings on the graduated scale are independent of the bore of the capillary tube. If a tube gets broken, it is, therefore, only necessary to replace it by another, without any fresh calibration of the instrument being necessary. Graduations are provided on the stem (H) to indicate the number of complete turns required to restore the mercury to the datum mark, and the edge of the screw is divided into 100 parts of about 1 mm. length, so that hundredths of a turn may be easily read when the stem is brought into a suitable position, as is usually done in the preliminary setting.

The reverse action takes place when the box is subjected to tension, by using the tail pieces (I) which act in the spherical-seated screw-nuts (J). The cylinder then stretches and its volume is increased. The level of the mercury column falls back into the box, and the plunger of the micrometer-screw must be advanced to force the mercury back to the zero mark. The tensile standardizing boxes shown in Fig. 2, Plate 14, are double-purpose instruments, and to convert them into compression calibrating boxes it is only necessary to take off the screw-nuts (J, Fig. 1, Plate 14), and the tail-pieces (I). As a precaution to ensure that the

testing-machine under trial should give a purely axial compression to these boxes, it is advisable to mount them on two end-pieces as shown in Fig 3, Plate 14. The bottom one is simply a hardened steel cylinder ground with perfectly smooth parallel faces, but the upper bolster is in the form of a spherical seating.

These boxes are comparatively light and very easily handled, and as the 30-ton size only weighs 20 lb., exclusive of the end-pieces, they are much more convenient to use than dead weights, against which they are, of course, very carefully calibrated in the maker's works. Much patient and careful workmanship is necessary in the construction of these instruments out of the most carefully selected and perfectly heat-treated material; but as the result of their researches and experience Dr. Alfred J. Amsler and Co. are able commercially to produce perfectly reliable and constant reading instruments. As an example of the minuteness with which the calibration of these boxes is executed, Table 3 (page 954) is given to show how standardizing box No. 150 for 30 tons tension or compression loading has been experimentally dealt with, and the English values engraved on the micrometer-screw derived from the plotted values of the constants by interpolation.

To check the accuracy of a testing-machine of any kind, by means of this standardizing box, the Authors have found it advisable to get the highest consistency in their readings by leaving the instrument in the machine for several hours under a slight load. This effects the complete equalization of the temperature of the box and the machine, and the instrument is handled as little as possible during the test. The level of the mercury column is first brought to about the middle of the capillary tube, the micrometer-stem being turned into a suitable position for reading, and there secured by a lock-nut. Next, the sliding mark is brought to a point just beyond the mercury column with the slit in it facing the operator. A slight motion of the micrometer-screw brings the mercury exactly to the outer edge of the mark, and the first micrometer reading is taken. Now the load is applied uniformly, keeping the micrometer-screw turning so as to maintain the mercury column near the inner edge of the datum mark. When the desired load is

attained and kept constant, the mercury level is brought up exactly to the outer edge of the zero mark, and the second micrometer reading taken. The difference is the number of turns corresponding to the load applied. The load is finally released gently, keeping the micrometer-screw turning in the opposite way to retain the mercury in the capillary tube; then when, the load is completely off, the level is again adjusted to the outer edge of the mark and a third reading taken. If there has been no temperature change, the final reading agrees with the first, but, if not, then the slightly different reading is noted, and a mean is taken of the two differences observed. The experiment is repeated, using an increased loading right up to the maximum limit of the box, and comparison is made with the values engraved on the handle of the micrometer.

Application of Elastic Column Dynamometer to Hardness Testing.— A new adaptation of this mercury-box load-measurer coupled with the micrometer-handle arrangement has recently been made by Dr. Alfred J. Amsler in connexion with a hand-operated screw-press with a maximum capacity of 5 tons (metric). Tests may be made with any form of this machine upon any material which does not fail or fracture under the load applied to it, such as, for example, in spring testing or in making hardness determinations of a metal, using either the Brinell ball or the Ludwik cone method.

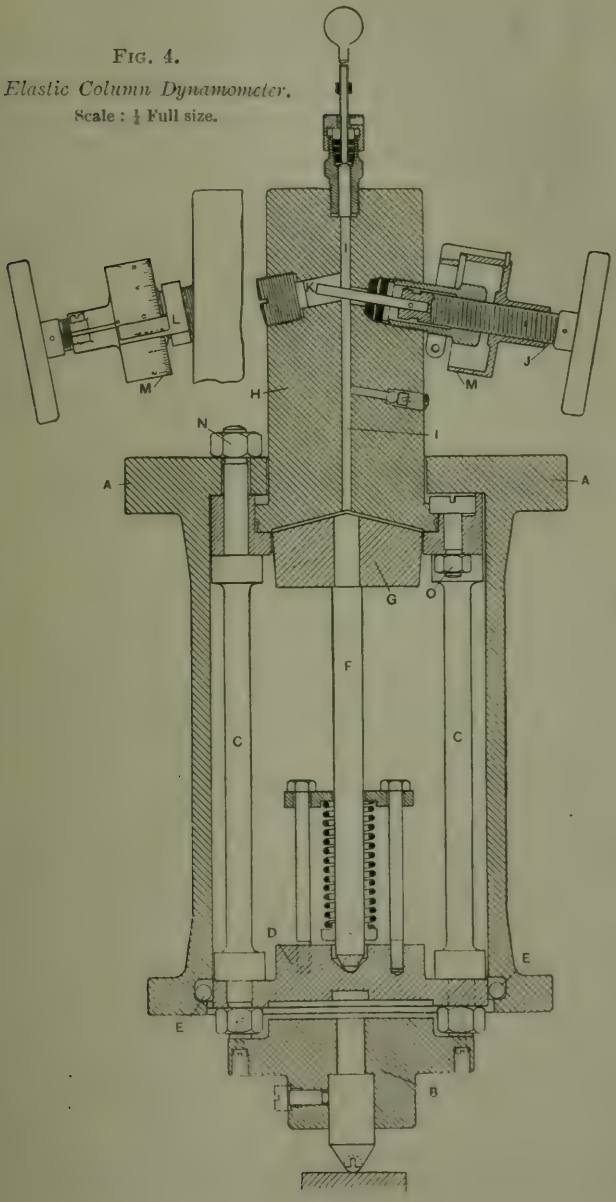
In the new form of dynamometer fitted in the movable head-stock of the press, use is made of the principle of the elastic deformation of three sufficiently strong steel columns to measure the load applied to the test-piece. The small amount by which these columns shorten under load is magnified by means of a mercury box, so that the volume of mercury expelled into a capillary glass tube can be measured in the same way as in the standardizing box by rotating a micrometer-screw handle. This returns the mercury level to the original datum point, and the load reading is taken directly from the graduations on the handle of the micrometer-screw, as formerly explained, in the calibrating box.

The construction of this dynamometer is shown in section in Fig 4. The body consists of a hollow casting, the top shoulders (A) of

Fig. 4.

Elastic Column Dynamometer.

Scale : ¼ Full size.



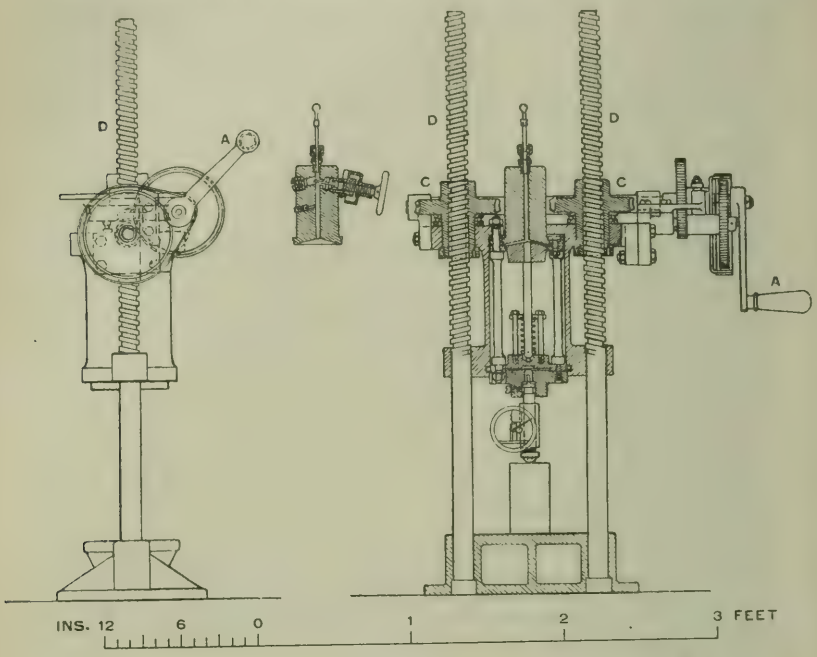
which are securely attached to the base of the press, not shown in this Fig. The compression plate (B) of the machine carries the indenting ball or cone, and is securely screwed to the lower ends of the elastic columns (C), and connects also with the yoke-plate (D), fitting loosely into the bottom of the dynamometer casing. This plate is able to move freely, being held in place by the balls (E), which are kept in their place in the groove by thick grease when the dynamometer is taken out of its casing. The load applied to the test-piece by the ball or cone is transmitted by the columns (C) to the shoulders (A), which provide the reaction. Under the compression load, the columns (C) shorten by a small amount, which is always proportional to the load they transmit, since they are designed to undergo no permanent deformation, thus acting as springs. The central column (F) is free to move so that it does not get stressed. It carries at the top end a piston (G) which moves a short distance into the space filled with mercury between the piston and the steel cylinder (H). The distance which the piston moves is equal to the amount by which the columns (C) become shortened, and as the tightness of the fit between the piston and the mercury space is ensured by a rubber membrane, the amount of mercury thus expelled into the capillary tube (I) is always proportional to the load applied to the compression plate (B), and thence to the specimen by the Brinell ball.

In order to measure the quantity of mercury expelled by the piston, use is made of the micrometer-screw (J), the point of which (K) projects into the mercury. On turning this screw, the level of the mercury in the capillary tube can be adjusted to any height, this being always brought back to the fixed datum mark to take the readings on the micrometer-screw handle. The amount by which the handle of the screw is turned is the measure of the load applied, the dimensions of the plunger (K) being such that one complete turn, read on the scale (L), corresponds to 1,000 kg. The scale on the drum (M) is divided into 100 parts, so that each part represents 10 kg. Thousandths of a turn can be estimated, thus giving the load reading to the nearest kilogram. The drum (M) is adjusted on the screw (J) so that the micrometer reading is

zero when there is no load on the press. The scale pointer (L) is fixed to the screw-carrier so that it can be adjusted, and this enables the pointer to be fixed in a position where it can be conveniently read. The arrangement for reading the load is quite independent of the bore of the capillary glass tube, since the reading is only taken after bringing the level of the mercury column back to the upper edge of the datum mark. In consequence, if the capillary tube is accidentally broken, it only needs to be replaced by another without there being the slightest necessity for restandardizing the press. This form of dynamometer thus forms a very exact and sensitive measuring device, and yet it is at the same time very strong, being absolutely unbreakable at the maximum load which it is designed to measure. The only part which may deteriorate after a long period of use is the rubber membrane, and immediately this sheet gets torn the fact is known by some drops of mercury escaping through the bottom of the apparatus. In order to change the rubber sheet the screws which project from the steel cylinder (H) are removed, then the screw-nuts (N) are taken off the top of the shoulders (A) and the whole dynamometer arrangement can be taken out from the bottom. By unscrewing the nuts (O) the cylinder (H) is freed, so that a new rubber membrane is stretched over the end of the cylinder and fixed there by a wire in the groove. The complete arrangement is then reassembled in the reverse order from that in which it is taken to pieces.

Description of Screw-Press.—A general view of the arrangement of the 5-ton screw-press used for making hardness tests by means of the elastic column dynamometer is given in Fig 5, Plate 15, which shows the machine making a ball indentation on a steel cylinder set on the base of the press. The construction of this strongly built machine is shown in Fig 6, which illustrates how the movable head-stock carries the dynamometer, and also the micrometer measurer for load determinations, on the straining-screws anchored in the base plate of the machine. By turning the handle (A) of the machine the direct action of two worms on the spindle (B) causes

the worm-wheels (C) to rotate on the right- and left-handed straining screws (D) so as to raise the head-stock quickly to admit a specimen up to 20 inches in height in the normal machine, or a wheel 6 feet high in the specially constructed presses. After the



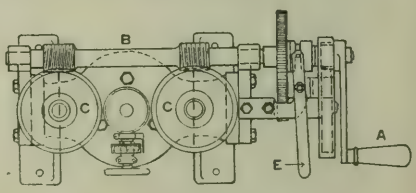


Fig. 6.—5,000 *Kg. Screw-Press for Hardness Tests with Ball or Cone.*

test-piece has been set level on the machine base, the handle is turned to bring down the ball or cone-carrying bolster at the bottom of the dynamometer attachment until it almost touches the metal surface to be indented. Then the slide-lever (E) is made to displace the spindle (B) axially so as to put in the reduction gearing and give the slow speed used for applying the load. As the loading

increases, the mercury column rises in the capillary tube above the position (about half-way up) where the datum mark has been fixed when the loading was zero and the micrometer reading was also nothing. As the right hand turns the press handle (A), the left hand can be used to rotate the micrometer-screw handle and thus maintain the level of the mercury column at or below the datum mark until the desired load is attained, when the mercury column is adjusted to coincide exactly with the top edge of the mark. Instead of this procedure, it is often preferable to set the micrometer-handle by three complete turns, thus corresponding to the 3,000 kg. usually applied to a 10-mm. ball, and then each time the load is applied to a specimen the level of the mercury is raised by the pressure applied till it reaches the top of the zero indicator. If this method is followed, it is occasionally advisable to make a zero adjustment by moving the sliding datum mark in order to eliminate any error which might arise in consequence of a temperature change.

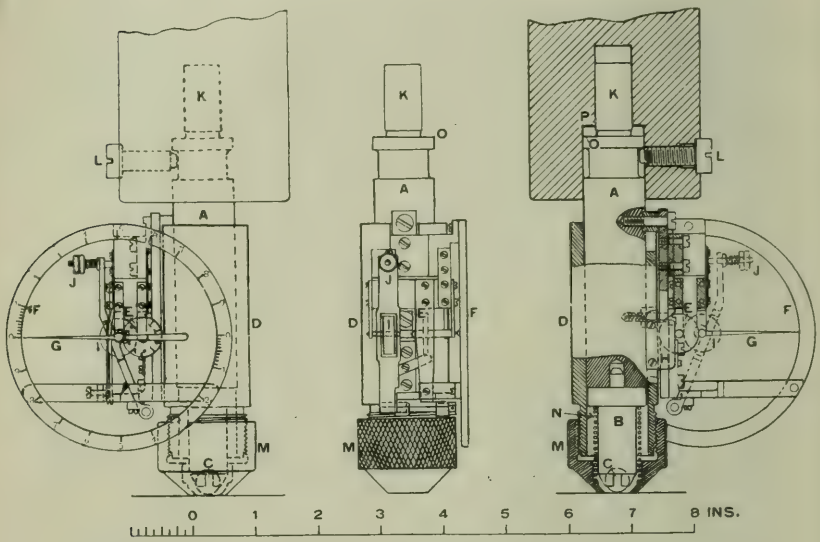
The desired load is maintained for a convenient period, say 15 or 30 seconds, and then the pressure is released by reversing the motion of the handle. In this way a number of tests can be quickly made, different sizes of test-piece requiring the position of the head-stock to be adjusted by the quick motion of the worm-wheels to attain a suitable initial position with the ball or cone just touching the smoothed surface of the specimen. The subsequent determination of the Brinell hardness in kg. per mm.^{2} may be done in the usual way of measuring the diameter of the imprint by a traversing screw microscope, or more conveniently by using a transparent celluloid taper-scale with the distance between the two divergent lines engraved in tenths of a millimetre on the underside next to the metal surface.

Use of the Depth Indicator and Graphs.—One of the strongest objections which may be raised against the common method of getting the hardness value of a piece of metal by the measurement of the imprint diameter is that the raised ridge caused in a soft piece of metal gives too large a reading. This gives too great a value to the area of the impression and hence too small a value to

the determined value of the hardness number. This is, of course, quite different from the low values got in excessively hard specimens due to the flattening of the ball under high pressures.

To obviate this serious objection, the Authors have found it extremely useful to employ a simple form of depth indicator, Fig. 7, Plate 15, for measuring the depth of the ball or cone imprint made in the test-piece whilst still in the machine. This little instrument

FIG. 8.—*Depth Indicator* (Amsler), *reading to* $\frac{1}{100}$*th mm.*



can be attached to the compression plate of the press in the bottom of the dynamometer attachment where the ball or cone punch is usually placed. It consists of a bolster (A), see Fig. 8, at the end of which can be fixed a punch (B), provided either with a ball (C) or a cone. The bolster slides easily inside the sheath made in the form of a hollow cylinder (D) which rests by its own weight on the test-piece, and on which is mounted the amplifying arrangement for indicating the depth of the imprint to the nearest $\frac{1}{100}$th of a millimetre. During the test, the ball or cone fixed at the end of the bolster penetrates the test-piece due to the load applied to it,

whilst the sheath of the instrument does not move with respect to the test-piece, so that the relative movement between the bolster and the sheath is exactly equal to the depth of the imprint produced.

The measurement of this depth to the nearest $\frac{1}{100}$th of a millimetre is done by means of two graduated dials, the smaller of which (E) indicates whole millimetres, and the large dial (F) records in $\frac{1}{100}$th of a millimetre The edge of the smaller dial is provided with very fine teeth which gear with a small wheel on the spindle of the pointer (G), which makes a complete revolution before the large dial for a depth of imprint of 2 millimetres. The spindle of the small dial is given its motion by engaging with a hardened steel plate (H) fixed to the sheath, and the pressure between the plate and the spindle necessary to prevent any slipping between them is ensured by adjusting the outer rim of the small ball-bearing (I) through screwing up a spring by the lock-nuts (J).

In making a hardness test with the depth indicator, the instrument is first fixed in the compression plate by passing the tail-piece (K) into the recess in the plate, where it should slide without friction. The weight of the indicator is carried by the screw (L), which simply keeps the instrument from falling without fixing it. The outer sheath (D), with the screwed-on, knurled feeler (M) falls to the bottom of its travel, whilst the punch (B), with the ball (C), is held up, due to the pressure of the helical spring (N). The feeler (M) first comes in contact with the piece of metal to be tested, and this, along with the casing (D), is lifted up until the ball also comes into contact with the specimen. The exact instant that this happens is readily observed, for so long as the feeler rises with respect to the ball, the pointer (G) turns round the dial (F), but it stops immediately the ball comes in contact with the test-piece, for then the relative motion of the feeler and the ball ceases. The ball punch (B) is now raised, along with the feeler (M) and the whole body of the instrument, until the surface (O) of the bolster comes in contact with the surface (P) of the compression plate. Whilst the instrument is traversing this distance the pointer is not moving, and during this time it should

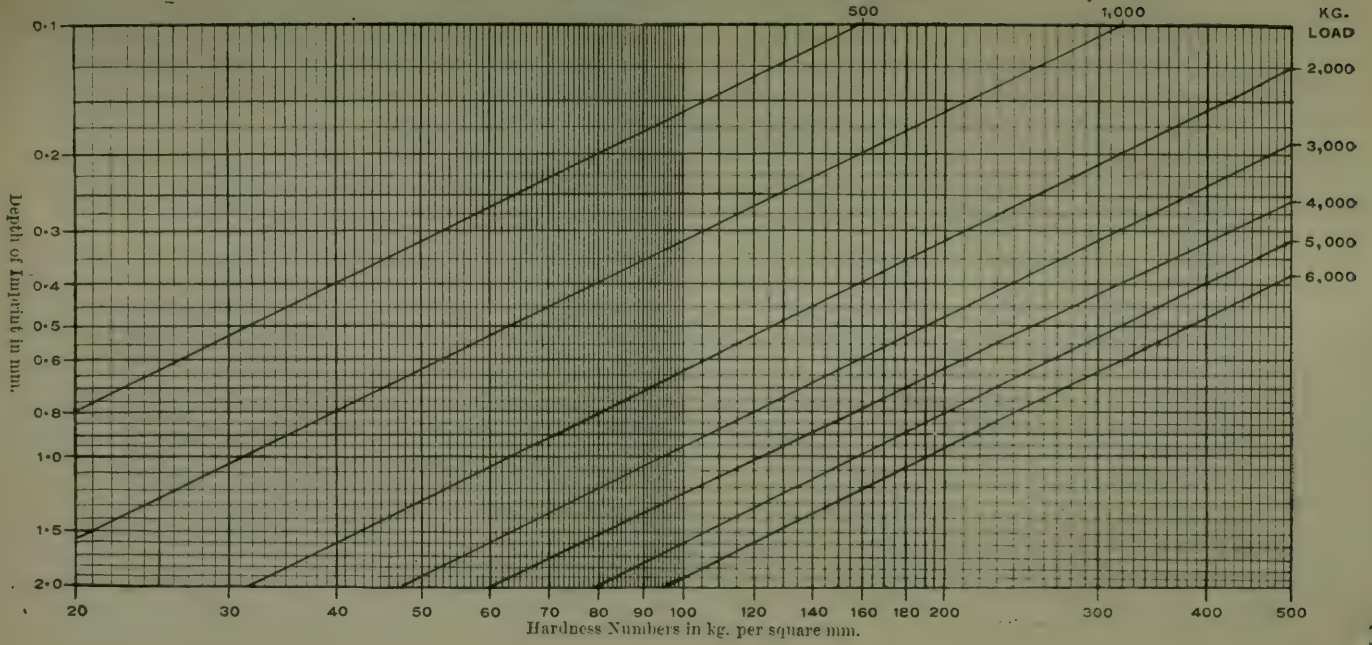
be adjusted to point to one of the zero marks on the dial. This is very easily done by turning the feeler (M) round on the screw of the sheath. The desired load is then applied, and the pointer will traverse the graduated dial so long as the ball is being indented into the metal under test. If the reading were to be taken whilst the specimen was still subjected to the full load it would not be correct, on account of the small amount of elastic deformation of the specimen, the ball, and also the depth indicator itself. In order to obviate this inaccuracy, it is necessary to release the load on the ball to almost nothing, retaining only a few kilograms pressure to keep the ball perfectly in contact with the imprint, before taking the correct reading of the depth, from which the hardness value in kilograms per square millimetre can be calculated from the simple formula :—$H = \frac{P}{\pi d t}$ where (d) is the ball diameter and (t) the depth of imprint in millimetres.

The hardness number obtained for a metal sample by using the depth of the imprint is always slightly different from that got by calculating from the measured diameter of the imprint. This difference is due in most cases to the raised ridge of metal produced round the imprint by the deformation of the test-piece. In measuring the diameter it is really the diameter of the raised ridge which is observed, whilst by measuring the depth of the imprint it is only the effective distance which the ball has penetrated the metal that is taken as the basis of calculation. Another advantage of the depth indicator is that it enables observations to be made of the way in which the depth of imprint varies with the loading as the test proceeds. It can also be used to measure a definite depth of penetration which may be taken as a standard ; the dynamometer of the screw-press is then used for determining the variable load required to produce this definite indentation. To save the awkward calculations which this method would entail, the Authors recommend the use of graphs prepared on logarithmically-squared paper, which reduces the parabolic curves got on ordinary squared paper to straight lines (as shown in Figs. 9, 10, and 11.)

The standardizing of the elastic column dynamometer as mounted

FIG. 9.—*Brinell 10 mm. Ball.*

Tests made with Pressure from 500 to 6,000 Kg.



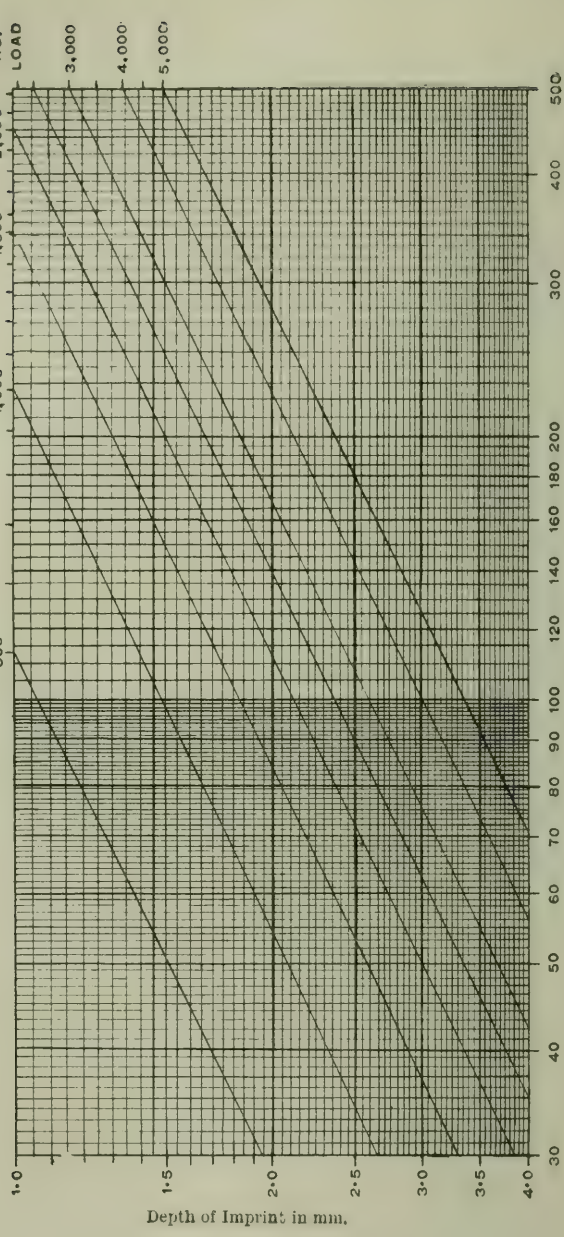
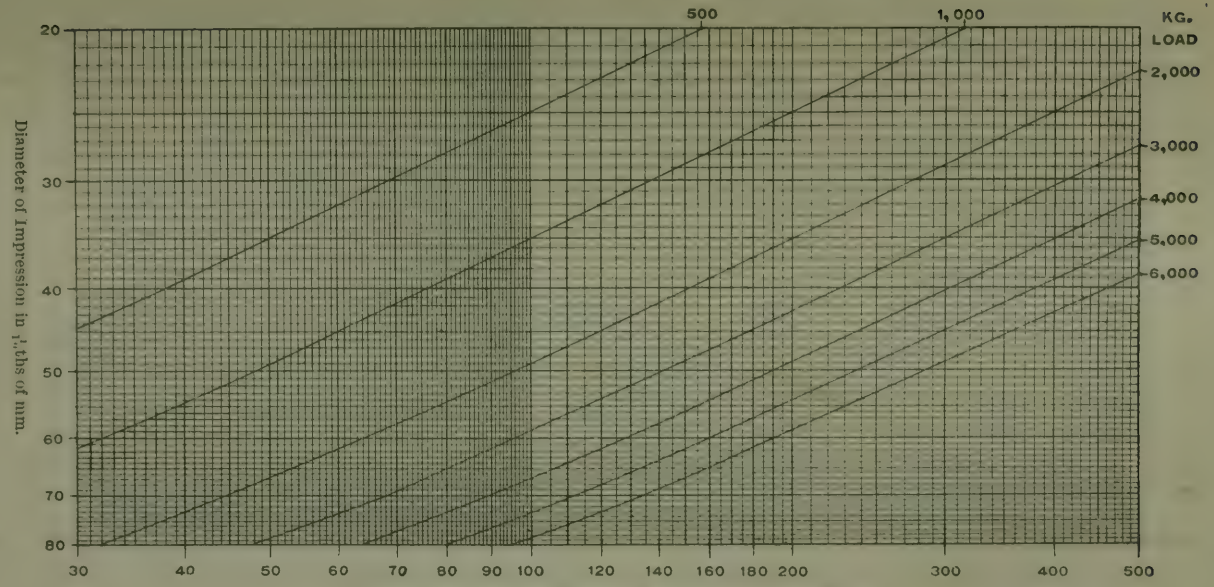


Fig. 10.—*Ludwik 90° Angle Cone.*
Tests made with Pressures from 500 to 5,000 Kg.

FIG. 11.—*Brinell Hardness.*

Tests made with 10 *mm. Ball and Pressures from* 500 *to* 6,000 *Kg.*

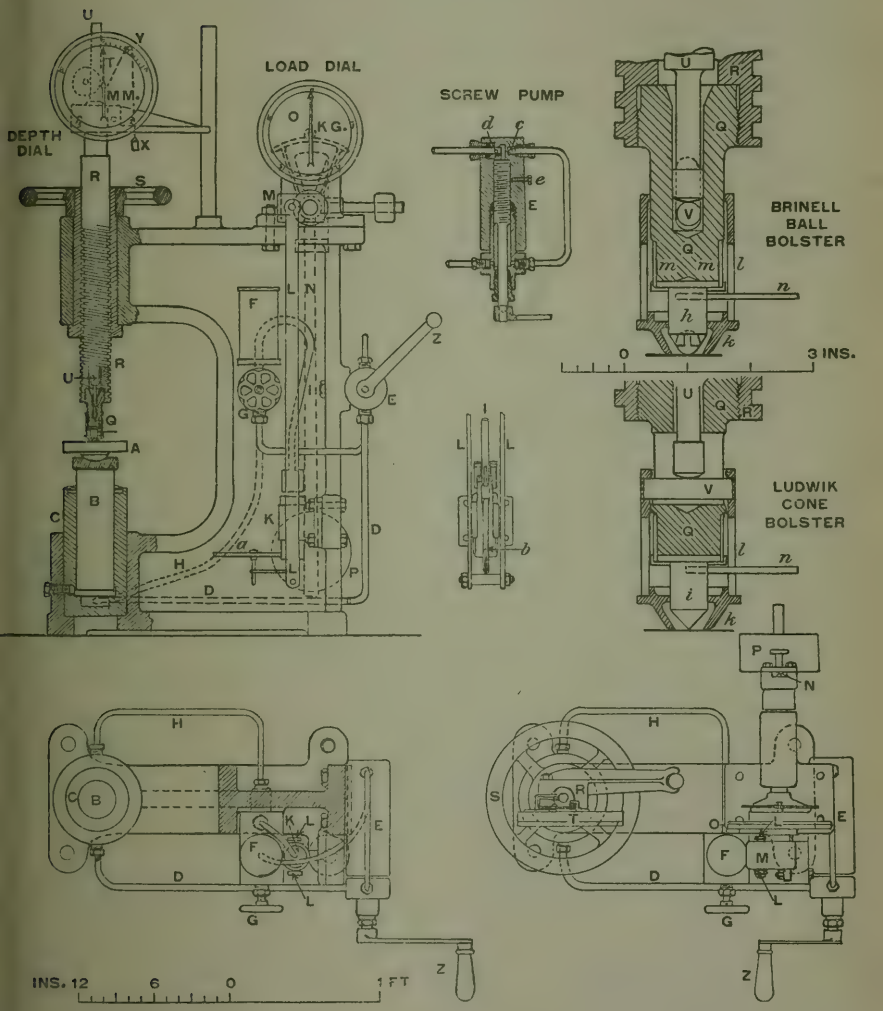


in the 5-ton press is very easily and simply accomplished. It is only necessary to hang the whole machine up by the compression plate in which the Brinell ball punch is mounted by using a suitably arranged cross-piece. The micrometer load indicator should then indicate exactly the net weight of the machine, about 300 lb., which may be easily determined beforehand by weighing it. Additional weights may then be placed on the machine base, or they may be suspended from the base by means of another cross-piece, and each new dead weight checked against the micrometer reading in kilograms.

Hardness Machine with Pendulum Dynamometer.—This machine combines into one complete outfit a depth indicator for accurately reading the depth of the ball or cone imprint made in a test-piece of metal by means of an oil-operated hydraulic press, the load indications of which can be varied in four degrees of sensitiveness up to 5 tons load, and the measurement of the loading applied is effected by means of a pendulum dynamometer. Fig. 12, Plate 15, illustrates the method of using the machine, which weighs 750 lb. It takes up a floor space of 2 feet by 1 foot, and is most conveniently set up on a table about 2 feet high so as to bring the two dials opposite the observer at a convenient height for easy reading. Details of the construction of this type of press on the well-known Amsler principle are given in the sectional drawings of Fig. 13, for the use of which the Authors have to thank Messrs. W. Reavell and Co., Ltd., Ipswich, one of the first users of this form of machine in this country.

The test-piece is set on the compression plate (A) resting in a spherical seating arranged on the top of the ram (B) of the oil press (C), the fitting of these two parts being sufficiently accurate to do away with the necessity for packing of any kind to ensure a suitable oil-tightness. A slight infiltration of oil between the ram and the cylinder walls enables the ram to be moved without friction, and a small tommy-bar enables the ram to be rotated by hand without any perceptible friction when the ram is not resting on the bottom of the cylinder, which must be assured before commencing a hardness test.

Fig. 13.—5,000 *Kg. Hardness Testing Machine.* (Amsler).



Oil under pressure enters the cylinder (C) from the pipe-line (D) leading from the pump body (E) mounted at the right-hand side of the machine frame. This screw-pump is operated by turning the handle (Z) in either direction, the necessary supply of oil for which is drawn from the reservoir (F), which should be partly filled with heavy machine oil. During the test the release valve (G) must be kept closed to prevent the pressure oil from returning by the pipe (H) to the reservoir (F), but communication is always open from the pipe (H) to the pipe-line (I). This pipe (I) is securely coupled to the cylinder (K), which can, however, be oscillated by the short lever (*a*) so as to eliminate any possible friction between the walls of (K) and the small piston (*b*), the area of which bears a definite relationship to the area of the ram (B). As the load is gradually applied to the test-piece, the small piston (*b*) tends to be expelled from the cylinder (K), and in doing so it carries down with it the stirrup connecting the two straps (L) at the bottom. These two rods (L) are connected at their top ends through the lever block (M), which is rocked over, and thus rotates in its ball bearings the spindle of the pendulum (N) forming the dynamometer, either alone or when loaded with the bob-weight (P). The displacement of the pendulum-rod (N) from the vertical provides the reaction which constantly balances the pressure of oil on the small piston (*b*), and hence the load applied to the test-piece by the ram (B).

When there is no load applied, the pendulum-rod (N) hangs vertically, and the pointer of the load dial (O) being held merely by friction is adjusted to zero when the ram (B) of the press cylinder (C) is just slightly raised. As the pendulum-rod is swung slowly out of plumb in balancing the load, the geared rack behind the dial rotates the spindle of the pointer and causes the hand to indicate the load, which can be raised to the desired amount by continuing to rotate the pump handle.

The ball or cone used to make the hardness imprint is mounted in the clip (*l*) by means of a pin (V) passing through a slot in the bolster (Q), which is securely screwed home in the lower end of the screwed rod (R) to effect a proper seating. This

straining-rod (R) can be raised or lowered quickly by turning the hand-wheel (S), which is not used for applying any of the load. At the top end of the screwed rod (R) is carried the depth indicator (U) which engages with the spindle of the pointer which passes over the face of the depth-indicator dial, reading up to 5 mm. and being graduated to show hundredths of a millimetre. As it is generally necessary to measure very small sizes of imprint depths, it is necessary to adjust the zero reading of the depth indicator very carefully while there is still no load acting on the test-piece. The surface ($m - m$) where the bolster (Q) touches the cone or ball punch must be quite free from oil, as this would be expelled under load and affect the depth reading.

To make this adjustment, the ball or cone is lowered at the end of the rod (R) by turning the handle (S) until the ball or cone almost touches the surface of the metal to be tested. Then the handle of the pump is turned to bring them together very slowly. At the instant when the ball or conical point just touches the specimen it is possible to feel an appreciable resistance being set up to the easy motion of the oscillating pin (n) inserted in the ball punch (h) or the cone punch (i). The raising of the specimen, set level on the platform (A) so that it does not rock, will have brought the feeler (k) resting on the test-piece surface into the same alignment as the ball surface or cone point, and immediately the ball or cone cannot be rotated on the specimen by the pin (n), then the milled head of the rod (U) is turned until the pointer of the dial (T) rests at zero. Then the rod (U) is pressed lightly to the right in order to ensure the least possible contact between the screw and the pinion, and this allows the rod (U) to move without appreciable resistance in a vertical direction. The weight X stretches the cord passing over the pulley Y, and tends to turn the pointer counter-clockwise.

By continuing to turn the pump handle (Z), first in one direction and then in the other, the ram (B) is raised, and the test-piece is pressed against the ball or the cone, the feeler remaining at rest on the surface, and thus setting up a relative movement with respect to the ball or cone which is indicated on the depth

dial. When the needle of the dial (O) points to the desired load, the lever (*a*) being meantime slowly oscillated, the pressure is maintained for a definite period, say 15 seconds, then the valve (G) is gently opened so that the ram (B) falls back by its own weight, forcing oil into the reservoir (F), and thus slowly decreasing the load. When the pointer of the dial (O) comes back nearly to zero, the pin (*n*) is taken in the left hand, and the handle of the valve (G) is operated by the right hand and kept open until the pin (*n*) is just able to be moved, with greater difficulty than when starting the test, and then the valve (G) is closed. A small load of several kilograms will still remain on the test-piece, and the depth reading is now made on the dial (T). If the reading of the imprint depth had been made whilst the impression was under the full load, the elastic deformation of the ball or cone, the bolster and the test-piece itself would have falsified the reading somewhat.

The sensitiveness of the dynamometer can instantly be changed from one degree to another simply by changing the point of suspension of the pendulum-rod (N). Four holes are found drilled in the rod (N) and marked with the numbers, 500, 1,000, 2,500 and 5,000, which represent the maximum load in kilos which can be attained when the pendulun is suspended by the pin passing through one of the holes into the guiding stirrup, and the pointer makes a complete revolution over the load dial (O). For the two lower loads the pendulum-bob is taken off, but for the two higher values it must be attached to the sliding-pin at the bottom of the pendulum-rod. Four graduated scales are attached by screws to the dial-plate (O), and care must be taken to read on the proper scale corresponding to the degree of sensitiveness selected for a particular hole by which to suspend the pendulum.

This machine is very rigidly and strongly constructed, and yet possesses a high degree of sensitiveness and accuracy. Both the ram (B) and the small piston (*b*) move quite freely when the ram is not at the bottom of the cylinder. The pendulum also swings quite freely when the straps (L) are raised from contact with the small piston (*b*). If, by any entry of air into the pipe-lines, the pump does not act, by simply loosening the screw (*e*) in the pump body

and turning the handle in a clockwise direction the air is expelled, and the screw is tightened up again. If by mischance any impurities are admitted by the heavy oil, these may prevent the ball valves (*c*) and (*d*) from resting properly on their seats, when they must be removed and cleaned as well as their seatings.

Results.—In conclusion some Tables are given to show the comparison between the hardness values obtained with several steel specimens tested by the different methods mentioned in the Paper.

TABLE 1.

Brinell Hardness with 10 *mm. ball and* 3,000 *kg. load.*

Quality of Steel.	From Diameter of Imprint.	From Depth of Imprint.	Average Increase due to Depth Reading.
B	121-126	127-136	8
C	149-156	159-166	10
D	187-197	191-203	5

TABLE 2.

Brinell Ball and Ludwik Cone Hardness tested on same specimen with different loads and methods of measuring imprint size.

Three Imprints made by:—	From Depth of Imprint at			Average.	From Diameter at 3,000 kg.	Average difference.
	1,000 kg.	2,000 kg.	3,000 kg.			
Ball	132	138	136	135	126	9
Cone	133	132	134	133	122	11

TABLE 3.

Schedule of Experimental Calibration of Amsler Standardizing Box No. 150, *for* 30 *tons tension and compression loads.*

Experimental Determinations.

Tension.			Compression.		
Loads in metric tons.	Readings. (Turns.)	Ratio, Reading ÷ Load.	Loads in metric tons.	Readings. (Turns.)	Ratio, Reading ÷ Load.
25·9	8·405	0·3245	26·1	8·322	0·3189
20·3	6·580	0·3241	20·5	6·561	0·3201
14·7	4·750	0·3231	14·9	4·784	0·3211
9·1	2·927	0·3217	9·3	2·984	0·3209
3·5	1·122	0·3207	3·7	1·195	0·3230
0·7	0·225	0·3214	0·9	0·290	0·3226
6·3	2·020	0·3206	6·5	2·092	0·3219
11·9	3·835	0·3223	12·1	3·882	0·3208
17·5	5·665	0·3237	17·7	5·667	0·3202
23·1	7·496	0·3245	23·3	7·439	0·3193
25·9	8·411	0·3247	26·1	8·319	0·3187

Interpolated Values.

Tension.				Compression.		
Loads in tons.	Interpolated Ratio, Reading ÷ Load.	Evaluated Constants. Turns for		Interpolated Ratio, Reading ÷ Load.	Evaluated Constants. Turns for	
		Metric tons.	English tons.		Metric tons.	English tons.
5	0·32105	1·605	1·631	0·3221	1·611	1·637
10	0·32220	3·222	3·274	0·3214	3·214	3·266
15	0·32320	4·848	4·926	0·32065	4·810	4·887
20	0·32405	6·481	6·585	0·3199	6·400	6·503
25	0·32475	8·119	8·249	0·3191	7·977	8·105
30	0·32540	9·762	9·919	0·3183	9·549	9·702

The Paper is illustrated by Plates 14 and 15 and 7 Figs. in the letterpress.

The Institution of Mechanical Engineers.

PROCEEDINGS

October 1920.

The First Ordinary General Meeting of the Session was held at The Institution, London, on Friday, 22nd October 1920, at Six o'clock p.m.; Captain H. Riall Sankey, C.B., C.B.E., R.E. (ret.), *President*, in the Chair.

The Minutes of the previous Meeting, held in Lincoln on 20th and 21st July, were read and confirmed.*

Retirement of Mr. Edgar Worthington.

The President said his first duty was to announce formally to the members the retirement of Mr. Worthington, the esteemed Secretary of the Institution. He felt sure they would desire to place on record their regret at Mr. Worthington's retirement, and also an appreciation of his long and faithful service. He became Secretary of the Institution in 1897, and had therefore served in that capacity for twenty-three years. Mr. Worthington was well known to the members; he was always ready to help, and he had the gift of making them feel at home when they came to the Institution, which, in his (the President's) opinion was one of the most important qualifications of a Secretary.

* Owing to a printer's error, the name of Mr. William Abbott was placed among the list of *Members* elected (page 587) instead of in the class of *Associate Members* (page 588).

(The President.)

It was now his duty to announce that the Council had selected a new Secretary for recommendation to the Members. Ninety-three applications had been received, and after weeding out a large number, seven were finally selected for interview, and eventually Brig.-General Mowat was unanimously selected. Brig.-General Mowat was an engineer of considerable eminence. He served throughout the War in various capacities, and his services were recognized by the award of the C.B.E. and by his being allowed to retain the rank of Brig.-General on retirement, which had only just taken place. He desired to read to the members the following abstract from a testimonial sent by Mr. Wordingham, a Past-President of the Institution of Electrical Engineers :—" Brig.-General Mowat is an engineer of wide and ripe experience, of a most suitable age, and his personal characteristics are exactly those which should make him an ideal Secretary—tactful, accustomed to directing, possessed of knowledge of men in different parts of the world, and a thoroughly nice fellow socially." He had much pleasure in formally moving : " That Brig.-General Magnus Mowat be, and is hereby, appointed Secretary to the Institution."

Mr. Philip S. Pitt said he had very great pleasure in seconding the Resolution.

The Resolution was then put to the Meeting, and carried unanimously.

The President said that Brig.-General Mowat was present, and perhaps he would like to say a few words in acknowledgment of his appointment.

Brig.-General Magnus Mowat, C.B.E., R.E. (T.F.), said he desired to thank the members from the bottom of his heart for the honour they had done him that evening. It would be his utmost endeavour to discharge the duties of Secretary to the best of his ability, and he thanked the members, one and all, for appointing him to the office.

The President said that, consequent upon the appointment of the new Secretary, the Council had decided upon the appointment of two Assistant Secretaries, namely, Mr. H. T. Chapman (who was known to all the members for his excellent work) for General Business, and Mr. J. E. Montgomrey for technical matters, proposals for membership, and for examinations. Mr. Montgomrey had been with the Institution since last March, and he had obtained the confidence of the Council, and especially of the Members of the Applications Committee with whom he came principally into contact. He thought Mr. Montgomrey would prove to be a most excellent member of the staff.

The President announced that, to fill the vacancy caused on the Council by the resignation of Mr. George Hughes, C.B.E., the Council had appointed Lieut.-Colonel A. E. Davidson, D.S.O., R.E., who, under Article 25, would retire at the next Annual General Meeting, but would be eligible for election. He hoped the members would be interested to know that this was the first occasion on which an officer of the Royal Engineers on the active list had been made a Member.

The President announced that the following 108 Candidates had been duly elected:—

MEMBERS.

Barry, Kenneth Alfred Wolfe, O.B.E.,	London.
Bellwood, Robert Aspland,	Hull.
Brown, James,	Greenock.
Dean, Frank,	Sheffield.
Glover, Arthur William,	Leeds.
Halsall, John Johnson,	Wigan.
Ross, Archibald John Campbell, C.B.E.,	Newcastle-on-Tyne.
Williams, William Thomas,	London.

ASSOCIATE MEMBERS.

Allan, Mossop,	Hobart, Tasmania.
Allan, Robert,	Luton.
Baird, James Oswald,	Glasgow.
Barber, Richard Fuller, Major, D.S.O., R.A.O.C.,	Dublin.

Beckwith, Harold,	Burton-on-Trent.
Bishop, Arthur Thomas,	London.
Boardman, Ernest Edward,	London.
Boswell, Harold,	London.
Butler, James,	Durban.
Campbell, Robert Hunter,	London.
Chadwick, James Wallace,	Bury.
Charlton, George Thomas Sarginson,	Glasgow.
Chicken, James Swinburne,	Newport, Mon.
Cornish, John Hewitt Martyn,	London.
Crighton, Spencer,	London.
Davison, Edward Leslie Poole,	Leicester.
Doole, Edgar, Lieut., Tanks Corps,	Wool.
Firmin, Frederick Walter,	Oulton Broad.
Flanders, Richard Leonard Howard,	Bristol.
Forder, Ernest,	Wolverhampton.
Fyffe, John Clark,	Sourabaya.
Gilmore, Edward Fitzgerald Gelstone,	Portsmouth.
Goddard, James Alan,	London.
Grundy, William Ernest,	Blackburn.
Harris, Frederick Pool,	Kuala Lumpur.
Hart, Arthur,	Birmingham.
Ironside, Martin,	Durban.
Jackson, William Alfred,	London.
Jeffes, Reginald,	Runcorn.
Johnson, Leslie,	Basingstoke.
Jones, William Arthur,	Stockton-on-Tees.
Jump, Percy,	Dudley.
Kingdom, Robert,	Cardiff.
Longmate, Henry Walter,	Thames Ditton.
Lubbock, Isaac,	Woolwich.
Lynas, Thomas Reid Ward,	London.
McDermott, Thomas Hugh,	Northfleet.
MacLean, Alan Douglas,	Southampton.
Marreco, Geoffrey Algernon Freire-,	London.
Marsden, James,	Khartoum.
Miller, James Lamont,	Calcutta.
Morris, Charles Edward,	Portsmouth.
Ogilvie, Gregor Macgregor,	Glasgow.
Ollier, Thomas Henry,	Crewe.
Perrott, Arthur,	Umtali.
Potts, John Garnet,	Bury.
Ridgway, William James,	Birmingham.
Robertson, Archibald,	Johannesburg.
Scott, Herbert,	London.
Sillcox, Lewis Ketcham,	Chicago.
Smith, Samuel Brown,	London.
Speir, Ronald Fitzhardinge,	Dunstable.
Stoddart, Robert,	Durham.
Strange, Henry Walter James, Major,	London.
Sutherland, Stuart Boyle,	Birmingham.
Tahourdin, Horace D'Albiac,	Ryde.
Thackeray, Edward Rawcliffe, Capt., R.A.O.C.,	Portsmouth.
Thom, Matthew, Capt., R.A.S.C.,	Liverpool.
Timmis, Colin,	London.
Travers, Lionel Arthur,	London.
Turner-Smith, Walter,	London.
Venning, Hubert Clarence William,	London.

Whittaker, William John,	Lowestoft.
Williams, James,	London.
Wilson, Charles Viereck, Lieut., R.A.S.C.,	Claydon.
Wood, William Bertram,	Thetford.
Zackariasen, Nicolai,	Glasgow.

GRADUATES.

Anderson, Robert Austin Temple,	London.
Bedford, Leslie Herbert,	London.
Boulding, Harold Stanley,	London.
Brooks, Walter Tom,	London.
Canaway, Alfred Thomas Ayling,	Portsmouth.
Carne, William Alfred,	London.
Chapman, Albert Roy,	London.
Cheesman, Eric Robert,	London.
Dancy, Wilfrid,	Brighton.
Diamond, Ernest Leontine,	London.
Harper, Harold James,	Brighton.
Hawkins, Alan Henry,	Birmingham.
Holmstrom, John Edwin,	London.
Hunt, Frederick John Allan,	London.
Hyams, Colin Michaelis,	London.
Hyams, Gordon Frank,	London.
Jones, Rupert Anthony Wilson,	London.
Kingham, George Philip,	London.
Knaggs, Frank Thomas,	Barrow-in-Furness.
Le Roy, Georges Joseph Guy,	London.
Macgregor, John Cameron,	London.
Maughan, James Douglas,	London.
Mizen, Douglas Henry,	London.
Molle, Norman Francis,	London.
Munford, William Herbert,	London.
Noël, Roger Joseph Marie Laurent,	London.
Ridley, Gerald Horace,	London.
Robertson, Leslie William Rose,	Derby.
Rowell, Kenneth,	London.
Saville, Reginald Thomas,	Rugby.
Tweedy, Robert Arthur Milford,	London.
Wilson, Allan James	London.
Wood, Joseph Harry Victor,	Birmingham.

The President announced that the following thirteen Transferences had been made:—

Associate Members to Members.

Blackburn, Robert, O.B.E.,	Leeds.
Burnside, George Barnhill, F.R.S.E.,	Shandon.
Cockburn, George Wilfrid,	Shanghai.
Dryburgh, Alexander Philip,	Jamshedpur.
Fairbairn-Crawford, Ivo Frank,	Newcastle-on-Tyne.
Frankau, George Neuberg,	Nagpur.
Halliday, Mark,	Durham.
Jones, Laurence Alban,	Birmingham.
Nobbs, Walter William,	London.

Shaw, William Morris,	Lymm.
Swingler, George Henry,	Cape Town.
Twells, John,	Kirkcudbright.
Woods, Ernest Edwin,	Bombay.

The President then delivered his Address.

The Meeting terminated at Half past Seven o'clock. The attendance was 151 Members and 59 Visitors.

The Institution of Mechanical Engineers.

EXTRAORDINARY GENERAL MEETING.

Immediately following the General Meeting, an Extraordinary General Meeting was held, the requisite quorum of thirty Members being present.

It was agreed that the notice convening the Meeting should be taken as read.

The President said the Extraordinary General Meeting had been convened for the purpose of considering, and, if thought fit, passing with or without amendment a certain Resolution, with a view to such Resolution being subsequently confirmed at a second Extraordinary General Meeting. He proposed, with the permission of the Members, first to consider Article 23a, as follows :—

> 23a. All Vice-Presidents who have served as such for a total number of eight years shall at the next following Annual General Meeting cease to be Vice-Presidents and shall become Past-Vice-Presidents, and other Vice-Presidents who have so served for a total number of six years may be appointed by the Council to be Past-Vice-Presidents and shall on being so appointed cease to be Vice-Presidents. No Past-Vice-President shall be eligible for the office of President.
>
> And by inserting in Article 24 before the words "Members of Council" the word "Ordinary."

The object of suggesting the new grade in the Council of Past-Vice-President was to increase the rate of promotion through the

(The President.)

Council, and therefore to be able to get new blood on the Council at an earlier date. He had much pleasure in moving the adoption of Article of 23A and the verbal addition in Article 24.

Mr. W. E. Berry formally seconded the Motion.

The President inquired whether any member desired to make any remarks upon the resolution before it was put to the meeting.

No member rising to speak, the President put the Resolution, and declared it carried *nem. con.*

The President then formally moved:—"That the Articles of Association of the Institution be altered by striking out Article 23 and substituting therefor the following new Article 23:—

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, twenty-one Ordinary Members of Council, not more than four Past-Presidents and not more than three Past-Vice-Presidents, to whom may be co-opted at the discretion of the Council the Chairman of any Local Branch of the Institution constituted in accordance with the By-laws while holding office.

The President, two Vice-Presidents, and seven Ordinary Members of Council shall retire at each Annual General Meeting, but shall be eligible for re-election.

The Vice-Presidents and Ordinary Members of Council to retire each year shall, unless the Council agree otherwise among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

The Past-Presidents, the Past-Vice-Presidents, and the Chairmen of Local Branches to serve upon the Council shall be appointed annually by the Council. They shall retire at each Annual General Meeting, but shall be eligible for reappointment.

Mr. E. W. Monkhouse formally seconded the Motion.

The President said that Mr. Ayres had proposed an amendment to the Article, and he would call upon him to explain it to the Meeting.

Mr. G. H. Ayres said that at the outset of his remarks he desired it to be clearly understood that, in proposing the amendments which he was about to move, there was not the slightest intention to infer disrespect for, or reflection upon, the personnel of the Council or the work they had done; on the contrary, their work and their kindly consideration of the needs and wishes of the younger members of the Institution were gratefully appreciated. As certain of the Articles of Association of the Institution had been re-drafted by the Council and were now presented for sanction, and further, in view of the obvious consideration which the Council themselves had given to the admittance of Associate Members to Council, as evidenced by the notice which appeared in the Journal of February last, Part I, page 9 (which he took to indicate their entertainment of the idea), the present moment seemed most opportune for advancement on the lines of those amendments which he proposed to move, and which were not formulated in any Bolshevik spirit of asserting what might be termed "The Rights of Associate Members," but that the presence of Associate Members on the Council would be wholly beneficial to the Institution as a body.

A Member suggested that Mr. Ayres should read his amendments, in order that the members might appreciate the speech he was making.

Mr. Ayres said he had purposely put his amendment in the form of three separate amendments, the first one of which followed the form sent out by the Institution on the slip convening the Meeting. The first amendment was:—

In Article 23 as proposed to be altered:

Line 1, after the word "Members" insert the words "and Associate Members."

Line 3, after the words "Ordinary Members of Council" insert the words "of whom fifteen shall be chosen from the class of Members and six from the class of Associate Members (subject to the conditions of sub-section (2) hereunder)."

(Mr. G. H. Ayres.)

Line 9, after the words "of Council" insert the words "of whom five shall be Members and two Associate Members (subject to the conditions of sub-section (2) hereunder)."

After paragraph 4 to insert a new sub-section (2), as follows:—

"That at each of the first three Annual General Meetings immediately following the passing of this Article, seven Ordinary Members of Council belonging to the class of Member shall retire, of whom five only may be re-elected; and the remaining two vacancies on the Council shall be filled by Associate Members; no Associate Member shall be required to retire from the Council until the fourth Annual General Meeting following the passing of this Article, when this sub-section automatically shall be withdrawn.

The second amendment was:—

In Article 23 as proposed to be altered:

After paragraph 4 to insert a new sub-section (1): "That if any Associate Member elected an Ordinary Member of Council be transferred to the class of Member during his term of office, he shall forthwith retire from the Council but shall be eligible for re-election as belonging to the class of Member at the next Annual General Meeting; and the casual vacancy so caused shall be filled by an Associate Member chosen by the Council, as provided by Article 25."

The third amendment was;

In Article 23 as proposed to be altered:

Lines 4 to 7 inclusive, omit the words "to whom may be co-opted at the discretion of the Council the Chairman of any local Branch of the Institution constituted in accordance with the By-laws while holding office" and substitute the words "together with the Chairman of any Local Branch of the Institution constituted in accordance with the By-laws while holding office."

Lines 15 and 16 omit the words "and the Chairmen of Local Branches."

Assuming Associate Members were admitted to the Council, the question arose as to what special functions they would fulfil to justify such recognition. In the first place he submitted that they would enable the closer linking together of the whole of the Institution's operations, and ensure greater continuity. Under the present conditions the excellent services rendered to the Institution by ex-Graduates, now Associate Members, who had worked hard on the Graduates' Association Committee for several years, was partially lost; yet such men had acquired a valuable experience, well-equipping them for service with the senior section Council, by virtue of their efforts on the Graduates' Association Committee.

There were also other Associate Members who had occupied offices in kindred societies who would be an acquisition, for they would be able directly to represent and advocate the needs of the younger members in a manner now impossible. Further, he was convinced that the presence of Associate Members amongst the Council on the President's "Front Bench" at the Meetings would be conducive to greater participation by the younger members in the discussions; for it required considerable "nerve" for a young member to approach a row of "distinguished gentlemen," probably twenty or thirty years his senior, in order to express his views to a meeting, or even to ask a question.

Again reverting to the work of the Graduates' Association, happily the Council had always encouraged the Graduates by one of their number occupying the Chair at the Graduates' Meetings, and whilst he would be the last person to desire the breaking of so happy a relationship, he did sincerely believe that, assuming Associate Members were admitted to the Council, a spirit of greater freedom would result if the Associate Members of the Council were generally to occupy the Chair at those Meetings, with the more senior Members of the Council, and, as formerly, he hoped the President, presiding on the more august occasions, such as the Annual Special Lecture.

Next there came what the President recently inaugurated and happily termed the "Stage Management Committee on Discussions," which should be largely, though not necessarily wholly, composed of Members of Council. If the Associate Members of Council were represented also, they could assuredly rope into the discussions the younger rank-and-file members because of their more intimate knowledge of the work pursued by members of corresponding age to themselves.

Having thus outlined what he considered the strong points in favour of the introduction of Associate Members to the Council, he would proceed to the more technical points involved by the amendments. The first point was the number of Associate Members to be elected, compared with the number of full Members. To his mind it was undesirable to enlarge the Council, and as the number

(Mr. G. H. Ayres.)

of Associate Members admitted should finally be a multiple of three, he considered the only number that could be decided on was six, if the representation was to be adequate. Correspondingly, therefore, the number of full Corporate Members would have to be reduced to fifteen. The difficulty then arose as to how and when the full complement of six Associate Members should be introduced, as it was obvious they could not be brought in all at once, because it would mean that, of the seven Members of Council retiring at the Annual General Meeting next following the alteration of the Articles, one only could be re-elected. That would be grossly unfair. He therefore suggested that two should be introduced each year until the full complement was obtained, and that correspondingly the full Corporate Members be reduced by two each year. That provision was the substance of sub-section (2). It would be further seen that at the Fourth Annual General Meeting following the passing of the Article, sub-section (2) would cease to be effective, and could, as he provided, be withdrawn automatically.

He would like to ask the President whether he should proceed to deal immediately with Amendment No. 2.

The PRESIDENT replied in the affirmative.

Mr. AYRES said he had simply asked the question because he desired to know whether the amendments were going to be put to the Meeting one at a time or altogether.

The second amendment was, to his mind, a necessary corollary to the first, and was framed in order to ensure that Associate Members were properly represented by Associate Members, for without it there was nothing to prevent an Associate Member elected an Ordinary Member of Council immediately being transferred to full Corporate Membership, and so defeating the object of the first amendment. More than that, he thought, he need not say; beyond perhaps the explanation that in putting the amendment forward there was no intention of suggesting that any Associate Member elevated to Council would be guilty of using

his office for the purpose of securing transfer to full Corporate Membership.

The third amendment affected more directly the interests of Provincial Members, and was in fact a reversion to the proposals formulated by the Council and circulated early in the present year. Perhaps in venturing to move the reversion he was guilty of greater audacity than in moving his other two amendments, but he did feël that, without wishing to belittle the discretion of the Council, as a matter of principle and policy all Local Branches should be treated absolutely uniformly; either (1) all Chairmen of Local Branches should be *ex-officio* Members of Council, or (2) should all be required to be elected to the Council in the usual manner, or else (3) should simply be invited to attend the Council Meetings whenever matters were under consideration which directly affected the particular Local Branch which they represented; but such attendance should not carry with it power to vote. Of these alternatives, the first appeared to him the soundest.

Mr. C. H. Woodfield said that he would second the amendments, in order to provide an opportunity for discussion.

The President said that the Council about two years ago took into consideration the suggestion that Associate Members should be eligible as Members of Council. Many discussions took place, both at the Council and at a special Committee which was formed for the purpose of considering that and similar matters, and finally they came to the conclusion that the time was not yet ripe to put Associate Members on the Council, and that was still the opinion of the Council. He did not think it was necessary for him to say any more in informing the members of what the Council felt on the subject.

Unless any member desired to make any remarks on the amendment, he proposed to put it to the Meeting immediately.

Mr. G. W. Thompson inquired whether it would be taken as a vote of censure on the Council if the amendments were passed.

The President replied in the negative.

Mr. G. W. Thompson said he desired to support the amendments, which were somewhat of a reminder of what he tried to get passed at the Meeting last February in another form. He seriously thought that the time had arrived when the Institution, with its 7,000 members, should try and bring about a closer friendship between the various members than they enjoyed at the present moment. There were not many members present at the Meeting who had the pleasure of knowing the Members of the Council as friends. He particularly desired to call attention to the fact that in the Resolution before the Meeting the word "co-opted" was used. He thought the members ought to be given the opportunity of nominating a member, when a vacancy arose, for the Council. The members had heard that evening that the Council had appointed someone to take somebody else's place on the Council—he did not know who it was—and he was sure there were not many members of the Institution who knew the gentleman at all.

Dr. H. S. Hele-Shaw, F.R.S. (Member of Council), interposing, said the Council never appointed anyone to take the place of a Member of Council who had resigned, who had not already previously been up for election as a Member of Council, and duly voted upon. The new Member of Council announced that evening had already been up for election, and therefore if any member of the Institution said that he did not know the gentleman at all, he was confessing that he had neglected to read the Ballot List for the election of Members of Council.

Mr. G. W. Thompson, continuing, said the statement that had just been made by Dr. Hele-Shaw did not, to his mind, alter the fact at all. Personally he thought the time had arrived when the 7,000 members of the Institution should receive more consideration. He was very pleased to hear the President say in the course of his Address that he thought there was room for improvement—at least, that was the inference he drew from the remarks that were made.

He lived in hopes that the members would yet see the Institution in a much more friendly character and paying greater attention to the social welfare of the Members, Associate Members, and any other individuals connected with the Institution. He had great pleasure in supporting the amendments that had been proposed.

Mr. Francis R. Wade, M.B.E., said that, as a Member of the Institution, he desired to support the amendment of the Associate Members. The President had himself that evening put forward the noble project of making the Institution a more live and useful body, and that could only be done by enabling all grades of the Institution to be represented on the Management Committee, whether it was called a Council or any other name. The time for co-operation by all grades was at hand. All grades in businesses or professions, whether they represented the heads of the Firm, the shareholders, or the workers, or the various grades of Membership of the Institution of Mechanical Engineers, should participate in the management of the concern with which they were connected; and the present was an opportunity to give representation to a lower grade in the Institution which would have the effect of revitalizing its energies.

Mr. William F. Cully inquired whether he would be in order in moving another amendment.

The President said another amendment would be in order, provided it was germane to the subject under consideration.

Mr. Cully said his amendment came within that category. He felt that the spirit of the amendment moved by Mr. Ayres was right; it represented a great feeling that existed amongst the Associate Members; but he also felt that there was too much of it to digest all at once. Without going into all those details, he desired to move as an amendment that in the first line of Article 23 the word "Corporate" should be inserted before the word "Members." He did not think there was any necessity to go into

(Mr. W. F. Cully.)
particulars of the further modifications arising from the amendment. If the Associate Members were not keen enough to elect members of their own body as Members of the Council, they did not deserve representation at all.

Mr. J. K. Aykroyd seconded the amendment, saying he agreed with Mr. Cully that the addition of the word "Corporate" was quite sufficient for the purpose. It seemed to him that Mr. Cully's amendment was a simplification of the previous amendment.

Sir John Dewrance, K.B.E., said he very much regretted the tone of the remarks of the members who had spoken on the subject, because the matter had been very fully discussed by the Council in quite a different spirit. At the present time the Council had the interests of all the Corporate Members before them all the time. The Council had not shown any desire, as far as he knew, to differentiate between the Associate Members and the other members. The only difference that existed in their privileges and circumstances was that one paid a less sum than the other as subscription to the Institution.

Mr. Cully, interposing, said that he certainly did not move his amendment with any such intention as Sir John Dewrance was imputing. He had simply moved his amendment for the benefit of the Institution.

Sir John Dewrance said that he was referring to those who had spoken in connexion with the first amendment. If the original amendment were accepted, the difficulty would be immediately created that two classes of members would be introduced into the Council. There was no difficulty whatever at the ordinary Meetings of the Institution in having two classes of members present; their ability to hear and speak was exactly the same, as were also their privileges. But if there were two classes of Members of Council, very great difficulty would be experienced in arriving at a just decision on many of the intricate matters that had to be decided.

It was impossible to get away from the fact that many of the Members and Associate Members were in the country; the Associate Members were the juniors of the Corporate Members of the Institution, and the expense of coming to London to attend the Council Meetings would be harder upon them than it would be upon the Members. There were other difficulties, but the real difficulty was that an Associate Member could always apply for transference to the position of a full member, and if he had such discretion, knowledge, judgment, education, and qualifications, and could afford to come to London to attend the Council Meetings, there was not the slightest reason why he should not make his application. The objection might also be raised to the amendment that had been moved that, if an Associate Member were elected to the Council, he was disqualified from making an application to become a Member of the Institution. He did not believe for one moment that the Council had in any way in the past neglected to listen to anything that an Associate Member had said, either at the discussions or with regard to any suggestions that had been put forward, or in any other respect; nor did he believe that any Member of the Council had done anything that would justify the suggestion that he was incapable of sympathizing or dealing with any class of members that existed in the Institution. Personally he would be extremely sorry to be associated with a Council where that kind of class distinction was introduced.

Mr. E. R. Dolby said he desired to make a few remarks with the object of simplifying the matter. Underlying the remarks of the mover of one of the amendments, it struck him that the idea was present in that gentleman's mind that the Associate Members as a class were to select a representative Associate Member to the Council. If that were so, he suggested that the same end could easily be met by letting Associate Members vote for a full Member who might represent their views on the Council.

Mr. Richard W. Allen, C.B.E. (Member of Council), said he

(Mr. Richard W. Allen, C.B.E.)
did not want the members to suppose that he was attempting to pour oil on the troubled waters, but he asked them to realize that the amendment which had been proposed might have a very great effect upon the future of the Institution. He did not wish to discuss the amendment and whether the case was made good or not, because the amendment which Mr. Ayres had moved had only been placed in the hands of the Council that afternoon, and they had not had sufficient time to think it over in order to appreciate what it really meant. He therefore suggested to Mr. Ayres that he should withdraw the amendment, and, if he thought fit to do so, bring it up at the next Annual General Meeting, when an opportunity would be afforded of discussing it as a special amendment after it had been printed in the Proceedings. He was most anxious that a "catch vote" should not be taken that evening on such an important question. He was too old a hand at that kind of thing, and he had seen a good Institution wrecked by what was called a "catch vote." The small number of members present at the Meeting that evening must remember that they represented over 7,000 members of the Institution, and whatever action they took that evening might be severely criticized by the 7,000 members all over the globe. He therefore begged Mr. Ayres to be a sportsman. Mr. Ayres had had an opportunity of explaining his views, which, however, personally he had not understood, and he believed there were many other members present who were in the same position. He therefore asked him to withdraw his amendment in order that the Council might consider it fully, and, if necessary, bring it up again at some other Meeting. He hoped Mr. Ayres would see his way to adopt that course and allow the Resolution, to which the Council had given considerable attention, to go through unchallenged.

Dr. H. S. Hele-Shaw (Member of Council) said that personally he saw not the slightest objection to accepting the amendment to insert the word "Corporate" before the word "Members." If it was the wish of the members to elect an Associate Member, he would heartily welcome the proposal, and they and many Graduates

had done magnificent work. He did not altogether agree with the remarks Sir John Dewrance had made about class warfare, as that was not intended by Mr. Ayres. He thought he knew, however, what Sir John meant, and he did not believe in distinction being made between Members and Associate Members. Really there was no distinction between different classes of Corporate Membership; except that of seniority and experience. Unfortunately many of those who sat at the Council table suffered from "*anno domini*." The younger men had not that complaint at present, but by-and-by, as years went on, they would be in the same position. He believed that he himself had gone through more elections than any other Member of the Council, although he was not the oldest member; and he would heartily welcome the election of any Associate Member to the Council, but he did not want that distinction to be made. He thought all the elaborate machinery which Mr. Ayres had mentioned, and which he was sure the members could not possibly have understood that evening, was dangerous. Personally, he would accept the amendment for the insertion of the word "Corporate" before the word "Members" with the greatest pleasure, but he would like their able President to state his views about it. If Mr. Ayres would withdraw the difficult and complex amendment which he had so ably put before them, he (Dr. Hele-Shaw) would be quite prepared to accept Mr. Cully's amendment, because he could see no harm whatever in it.

The PRESIDENT said he was afraid he could not answer Dr. Hele-Shaw's remarks without letting "a cat out of the bag," namely, that personally he did not object to Associate Members being on the Council. It was too late in the evening to go into the whole question, but there were in his opinion objections to the amendments that had been moved. As he had previously stated, the Council had considered the matter very carefully and were prepared to consider it again with any further light that might be brought to bear upon it. With regard to Mr. Ayres' amendment, there were many points the effect of which he confessed he did not appreciate. The amendment might be all right, but on the other

(The President.)

hand it might not, and he therefore joined with Mr. Allen in asking Mr. Ayres to withdraw it. He also asked Mr. Cully to do the same with his amendment, on the understanding that the Council would be prepared to consider the matter again and get the Associate Members together and discuss it with them, so that at a later date further action could be taken. The insertion of the word "Corporate," as proposed by Mr. Cully, was open to the danger that it might happen, that in course of time, all the Members of Council would be Associate Members, and he did not think anybody would suggest that. There would have to be some limitation to the number of Associate Members on the Council, and that would have to be put into any Resolution that was moved; there were many other points that might be raised.

Mr. G. H. Ayres said the real purpose for which he moved the amendments had been achieved. He did not wish to obtain a "catch vote" on any such amendments, because he realized that that might be very dangerous to the Institution, and he would be the last member to wish the Institution to lose any of its dignity in such a manner. In view of the assurance that had been given by the President on behalf of the Council, he had the greatest pleasure in withdrawing his amendments for the time being.

Mr. William F. Cully said that he also had much pleasure in withdrawing his amendment. A spirit, however, seemed to have been engendered that was very far away from his thoughts when he moved the amendment. He simply looked at the matter as a question of principle. There was a very large body of Associate Members who were unrepresented; but he was content to leave it to the Council to see that they were properly represented in the future.

The President thanked Mr. Ayres and Mr. Cully for withdrawing their amendments, and said he was sure the members would also thank Mr. Ayres for having brought the subject to their notice. It was one which required ventilating, and he assured the members that the Council would take it into very earnest consideration.

The two amendments having been withdrawn, he would now put the original Resolution which had been proposed and seconded.

The Resolution was then put and declared by the President carried *nem. con.*

The President announced that a confirmatory Meeting would be held on Friday, November 19th, at 10 minutes to 6 p.m. No further amendment to the Resolution could then be made.

The Meeting then terminated.

CONVERSAZIONE.

A Conversazione was held at the Institution on Thursday evening, 21st October 1920, which was attended by about 730 Ladies and Gentlemen, who were received by the President, Mrs. Sankey, and the Council. During the evening vocal and instrumental music was given in the Library, and a number of pictures of engineering interest were shown on the Kinematograph.

THE COEFFICIENT OF DISCHARGE OF ELEMENTARY NOZZLES.

By A. A. JUDE, of Birmingham, *Member.*

[*With written Discussion.*]

Introduction.—In the Author's contribution to the discussion on Professor Henderson's Paper of 1913, the suggestion was made that the coefficients of discharge of any kind of orifice or nozzle could be conveniently and rapidly made by arranging the test-nozzle in series with a standard or datum nozzle, the absolute coefficient of which was known with tolerable accuracy. The intervention of the War has naturally put a very considerable brake upon researches in these matters, and there yet remains to be ascertained the absolute coefficient of some datum nozzle, particularly within the super-critical range of pressure ratios. For the fact remains that neither the Rateau nor the Hirn experiments provide it satisfactorily, and it may be presupposed by their incidence that their predecessors do not provide it. It was, moreover, a disappointment to the Author that Dr. Morley's experiments * do not provide it, in spite of a careful elaboration of apparatus.

The present Paper again does not provide it, but it endeavours to clear away a considerable amount of the unsatisfactory features

* Proc. I.Mech.E. 1916. "The Flow of Air Through Nozzles."

surrounding the previous experimental results, and to indicate exactly what is wanted, and probably can be provided with existing apparatus (Morley's for example), without the Author or anyone else going to the unnecessary expense of duplicating it more or less. The "reservoir apparatus" is apparently the *ultima ratio* in the matter, but it is cumbersome and comparatively slow working; and, as previously stated, once the required datum spot is obtained, there is no need to have much, if any, future recourse to it.

For the sake of clarity it may be as well to point out here that Dr. Morley dealt exclusively with sub-critical pressure ratios, particularly in regard to convergo-divergent nozzles, and incidentally to their various components, whereas the present Paper deals more particularly with super-critical ratios in regard to wholly convergent nozzles, and the "hole-in-a-thin-plate," which is also the case with the Rateau and Rateau-Hirn references. Dr. Morley does deal, somewhat casually it is considered, with the "hole-in-a-thin-plate" (H.T.P.), but his H.T.P. is by no means that article even in the approximate sense of the word. Some other necessary criticism of his experiments will appear later on in the text.

The Author has noted that a number of experiments have been made with the series apparatus by A. L. Westcott, the results of which were published in *Power* and *The Mechanical World*, February 1916, the experiments apparently being made primarily for the instruction of students. He has not heard of any others, although, of course, there may be some. But here, again, in the Westcott experiments a constant coefficient has been assumed for the datum nozzle, and the discharge referred to the semi-empirical formula of Fleigner, itself built on more or less approximate and over-all constant assumptions. So, in short, coefficients of discharge are pretty much as indefinite as they were twenty years ago.

The objects, then, of the present Paper are:—

(1) To draw out the potentialities of the series apparatus and so establish a ground for confidence (or rejection) in it which appears to be lacking

(2) To clear up the unsatisfactory features relating particularly to the variability of the coefficient over the super-critical range.

Most previous experimenters decide that the coefficient of discharge of nozzles varies (for example) from, say, 0·93 at $\frac{p_2}{p_1}=1$ to 0·98 at the critical drop. But this is hardly satisfactory, especially as the coefficient apparently bears no very simple relation to $\frac{p_2}{p_1}$. Such loosely coherent values are therefore useless as data of precision.

A reference to and discussion of the Rateau and Hirn experiments enters somewhat prominently in the present text, largely for the reason that they are the most important extant to which the Author's experiments bear a deliberate relation, as will be seen.

Assuming for the moment the impeccability of the series apparatus, it clearly does not matter very much what datum nozzle is adopted so long as its coefficient is known for all practicable ratios of $\frac{p_2}{p_1}$, but there may be some practical convenience in some one form over another. For many experiments of an approximate character, such as those given by the Author (Proc. I.Mech.E., 1913, page 294), it is quite near enough to assume a constant datum coefficient, but this by no means disposes of the necessity for the unarbitrary standard. Obviously it would be a great convenience to have a nozzle of constant unity efficiency. Does such a unity nozzle exist? Probably not. But numerous experiments lead to the conclusion that the convergent nozzle without an appendage (or parallel extension of the throat, defined by the Author as a "tail" in Proc. 1913) has a coefficient not far removed from unity, but sufficiently far to be inconvenient sometimes. Rateau emphasizes that with steam it is unity at a very little less than the critical drop, about $\frac{1}{4}$ per cent greater thereat, and that it varies from 0·95 upwards over the super-critical range

With air (as reinterpreted by Rateau) Hirn obtains almost unity over the whole range, but no precise values are advanced except at the critical drop where the excess is apparently about

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FIG. 1.

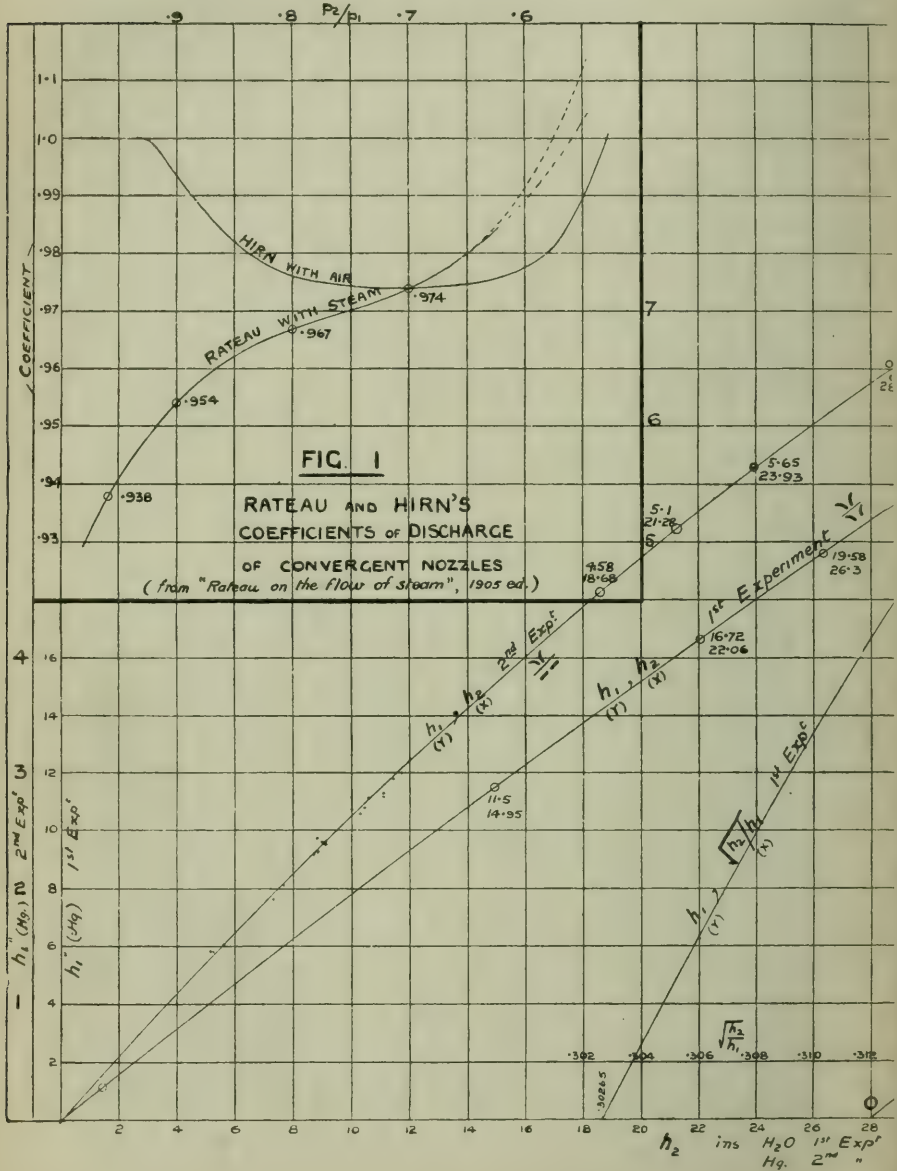

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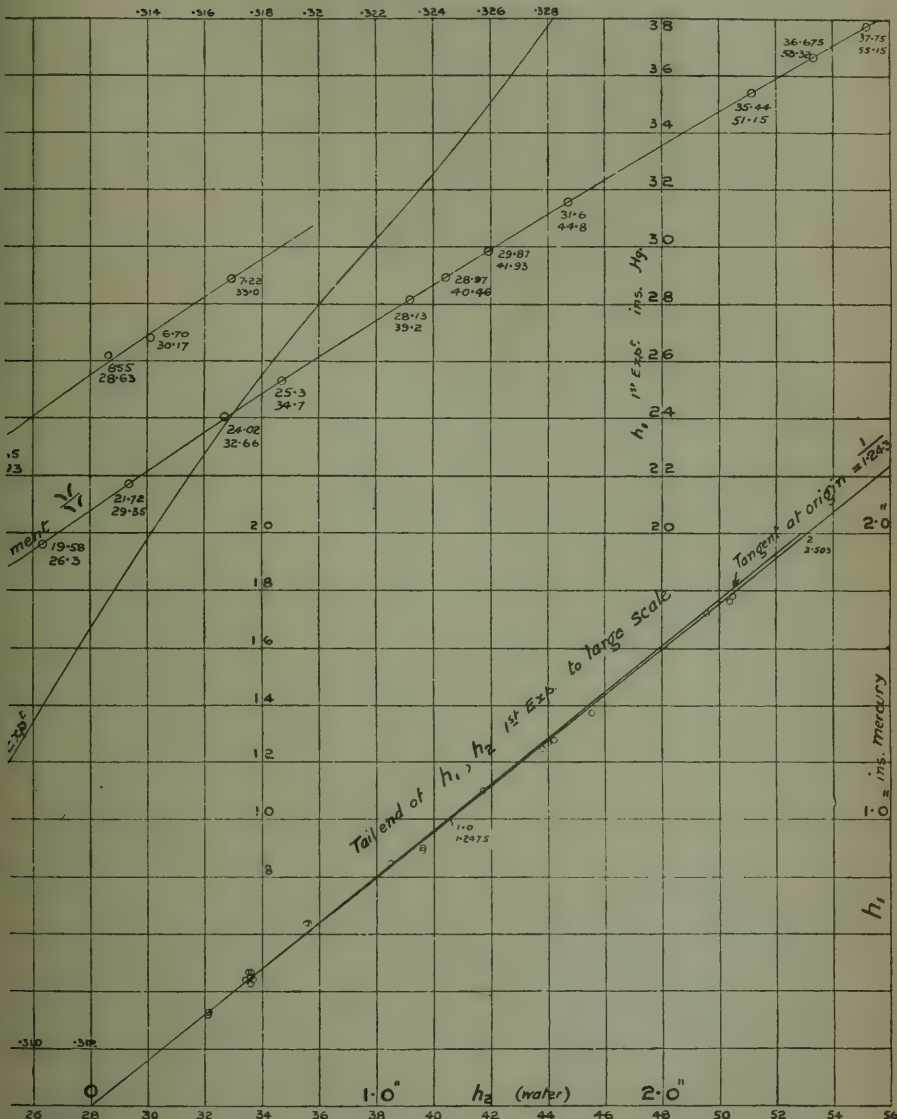
FIG. 3.—*Experimental Data.*



$\frac{3}{4}$ per cent. For the "hole-in-a-thin-plate" with "very small heads," presumably a few inches of water, which would give $\frac{p_2}{p_1}$ greater than, say, 0·985, a value of 0·633 is given.

The Rateau diagram is somewhat unfortunately constructed for showing the coefficient of discharge, which after all is just the thing one wants to know most of all from that diagram. The coefficients as actually stated in figures have therefore been set out afresh to large scale, Fig. 1 (page 980).

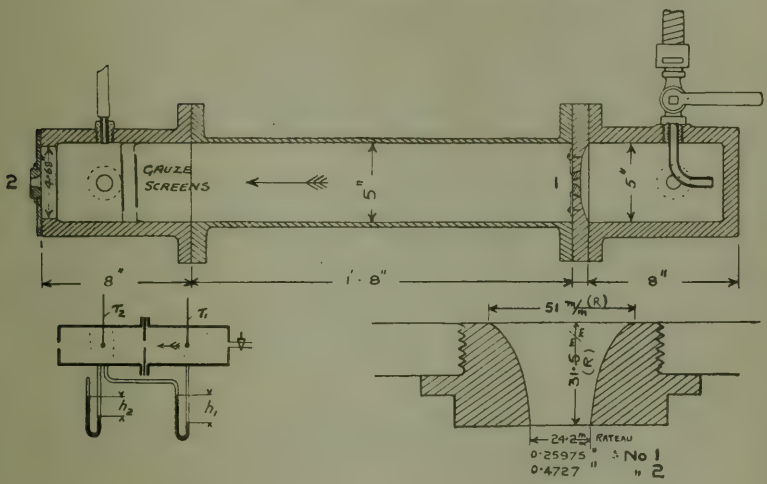
Referring to Fig. 1, it may be asked—"to where does the left branch proceed—zero, or what? And as it falls away rapidly at beyond $\frac{p_2}{p_1} = 0{\cdot}8$ (a most useful and common range of application), whence arises the almost universal assumption that the coefficient is approximately constant?" 0·92 to 0·97, or thereabout, is by no means a constant; indeed, it is a disconcerting variation, particularly as the Rateau and Hirn values diverge widely in value and characteristic, Fig. 1. Suppose, for instance, an air-compressor were being tested by means of such a nozzle—a common procedure—with a small drop of pressure! Apparently the credentials of the nozzle do not exist even to a degree within the usual commercial margin, and it is not surprising that there is a considerable measure of preference for "pump-up" tests where such are feasible. It has occurred to the Author that if two similar nozzles of different size be placed in the series apparatus, a disentanglement of these knots might ensue. A discussion of his experiments on these lines will therefore now follow.

Experiments with Convergent Nozzles.—Fig. 2 shows the series apparatus used. The long middle tube was inserted specially to meet a reasonable criticism that nozzle 2 might be subjected to disturbing eddies from nozzle 1. As a matter of fact, absolutely no difference in the readings could be detected with and without it. Moreover, as is perhaps well known by those used to nozzle experiments, an obstruction can be placed within a diameter or two

from the outlet of a nozzle without affecting its discharge; and further, it is to be observed that the smaller nozzle was inside.

In the example of relative coefficients given in the discussion of Professor Henderson's Paper of 1913, it was stated in other words that the relative coefficients c were given simply by the hydraulic formula $c_1 a_1 \sqrt{h_1} = c_2 a_2 \sqrt{h_2}$, where a is area and h head of pressure in inches of the same medium. This does apply very exactly for very small heads at atmospheric pressure such as a few

FIG. 2.—*Series Apparatus and Converging Nozzle.*



inches of water, especially as in the experiments referred to the coefficients of the test and datum nozzles were varying at approximately the same rate, but of course the expression is not applicable to large heads of pressure, or heads at a comparatively low absolute level, or for a more rigorous analysis. The usual adiabatic or so-called isentropic formula will therefore be used. (It is not conceded that this formula is quite the proper basis. A coefficient of discharge is the ratio of the actual discharge to that expected by a more or less arbitrary ideal.)

Let $\frac{p_1}{p_2}1$ (symbol (1) for convenience in printing) be the inverse pressure ratio applied to the first nozzle

$\frac{p_1}{p_2}2$ (symbol (2) do. do.) do second nozzle.

a_1, a_2 the nozzle outlet areas.

τ_1, τ_2 the absolute temperature at inlet.

h_1, h_2 the experimental differences of pressure in inches of mercury.

c_1, c_2 coefficient of discharge.

$x = \frac{\gamma - 1}{\gamma}$.

Then, neglecting velocity at entry, the well-known formulæ* take the following form :—

$$\frac{c_1}{c_2} = \frac{a_2}{a_1} \times \frac{1}{(2)} \times \sqrt{\frac{\tau_1}{\tau_2} \frac{(2)^x}{(1)^x} \left\{ \frac{(2)^x - 1}{(1)^x - 1} \right\}} \quad . \quad . \quad (a)$$

---

* Considering the inlet and outlet conditions of a nozzle, and adopting familiar notation (not specifically that of the text above)—

$$E = \frac{v_2^2 - v_1^2}{2g} \text{ per lb.} = p_1 \nu_1 \frac{\gamma}{\gamma - 1} \left\{ 1 - \left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right\} \quad . \quad . \quad (1)$$

$$\frac{Q}{c} = \frac{Av}{\nu} = \frac{A_1 v_1}{\nu_1} = \frac{A_2 v_2}{\nu_2}. \quad \text{Let } \frac{A_1}{A_2} = m,$$

Then $$v_1 = v_2 \frac{1}{m} \cdot \frac{\nu_1}{\nu_2} = v_2 \frac{1}{m} \left(\frac{p_2}{p_1} \right)^{\frac{1}{\gamma}}. \quad \text{Also } p\nu = R\tau.$$

Hence (1) becomes—

$$\frac{v_2^2}{2g} = \frac{R\tau_1 \frac{\gamma}{\gamma - 1} \left\{ 1 - \left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right\}}{1 - \frac{1}{m^2} \left(\frac{p_2}{p_1} \right)^{\frac{2}{\gamma}}} \quad . \quad . \quad . \quad . \quad (2)$$

For two nozzles in series,

$$Q = \frac{{}_1A_2 \times {}_1v_2}{{}_1\nu_2} c_1 = \frac{{}_2A_2 \times {}_2v_2}{{}_2\nu_2} c_2,$$

or $$\frac{c_1}{c_2} = \frac{{}_2A_2 \cdot {}_2v_2 \cdot {}_1\nu_2}{{}_1A_2 \cdot {}_1v_2 \cdot {}_2\nu_2} \quad . \quad . \quad . \quad . \quad (3)$$

Rearranging the suffices and symbols as in the text, (2) applied to the numerator and denominator of (3) yields formulæ (a) × (b).

Including the velocity at entry, this has to be multiplied by the factor—

$$\sqrt{\frac{1-\frac{1}{m^2}\cdot\frac{1}{(1)^{2/\gamma}}}{1-\frac{1}{n^2}\frac{1}{(2)^{2/\gamma}}}} \quad . \quad . \quad . \quad . \quad . \quad (b)$$

where $m = \frac{\text{body area 1}}{a_1}$ and $n = \frac{\text{body area 2}}{a_2}$.

Ordinarily (b) is negligible, only appearing in the fifth and sixth places of decimals in the two experiments, but in the present case it is not quite negligible, more particularly in the consideration of the limits, as will be seen.

The experimental nozzles of the first series were replicas of Rateau's No. 3 nozzle, with the exception that the outer walls were flat as shown in Fig. 2, and not scalloped as in the original. The inner one 1 was 0·25975 inch diameter (area $a_1 = 0{\cdot}052991$), and the outer one 2 was 0·4727 inch diameter (area $a_2 = 0{\cdot}1755$). The respective diameters were gauged and checked by means of several long tapered mandrels at the same time, and with the same micrometer, and the relative accuracy of the gauging is certainly within the order of 1 in 10,000. (The relative diameters are the important thing with the series apparatus.) Air was supplied from the pneumatic mains, at some hundred yards from the source, and at the end of a considerable pipe ramification. With the works drawing largely upon the supply at the same time, the question of vesicular moisture was eliminated. The humidity was practically 40 per cent constant, and remarks on the adjustment for this factor are made farther on. In the meantime it does not enter the problem, and it is only a matter of selecting the index γ in the conclusion. The pressures for the readings were set at random, and ordinarily it is the Author's practice to take a very large number in any one experiment of what might be called "snatch" readings, in which it is quite unnecessary to be over-particular to small fractions of an inch, because error is faired out with great precision by the resultant curve. In the present case, however, to avoid a criticism which is quite reasonable by those not used to the apparatus, a number of precise steady readings, each many times

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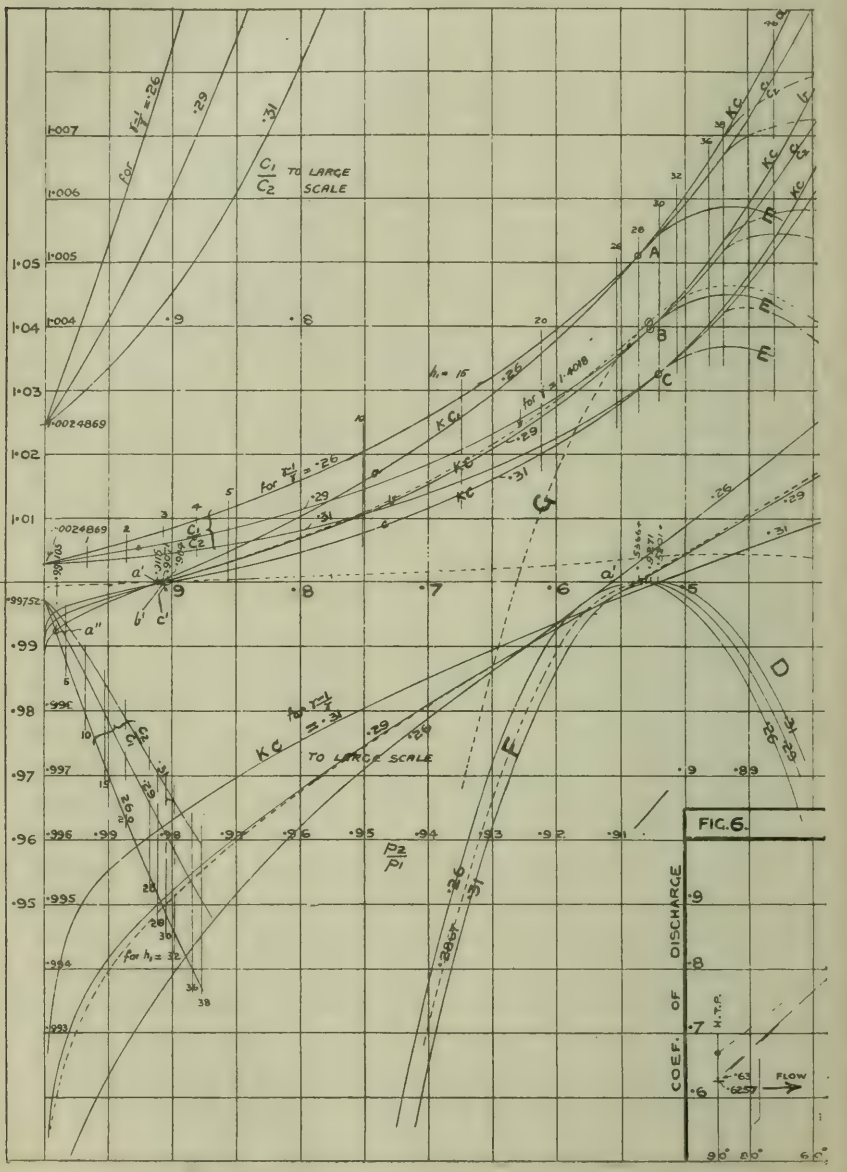
FIG. 4.—*Data for*



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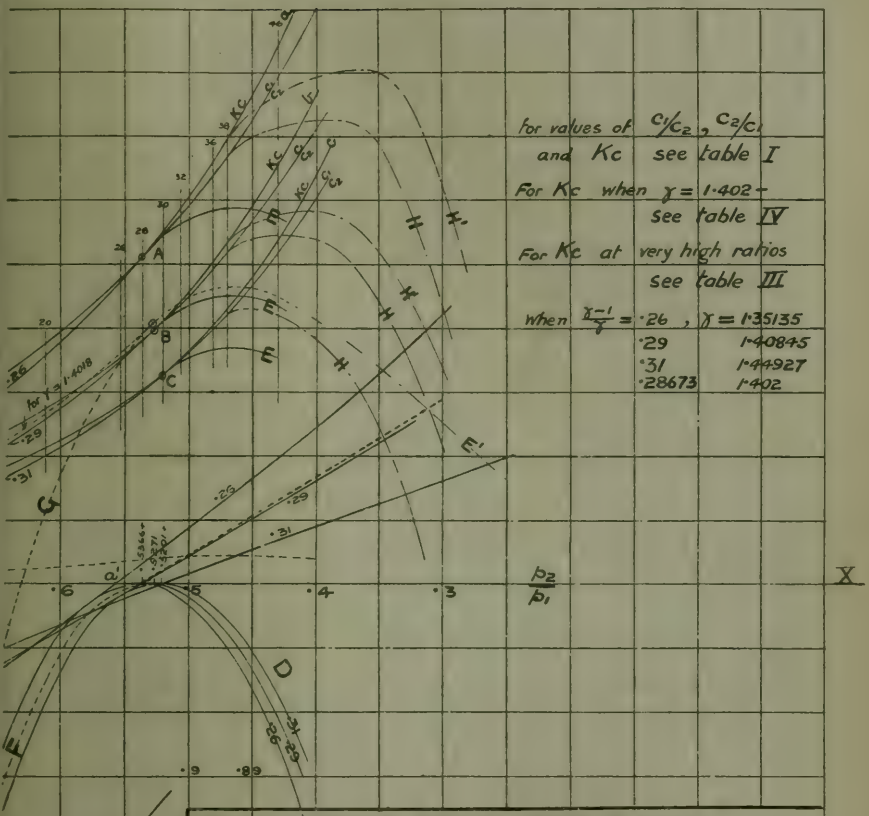
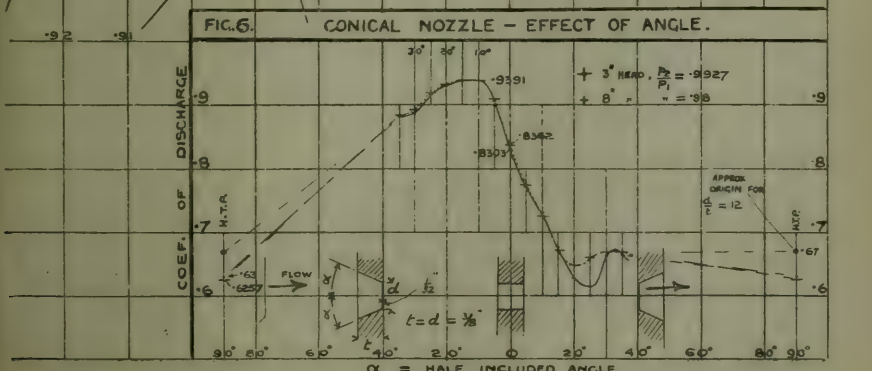
Converging Nozzle.





repeated, were taken. These are plotted and figured in Fig. 3 (pages 980–1). The hundred and one other points are not shown.

From this curve Table 1 (pages 1012–3) has been built, and the concluding curves of $\frac{c_1}{c_2}$, $\frac{c_2}{c_1}$ set out in Fig. 4 (pages 986–7). The table of Kc is derived from Fig. 4, as will be explained.

t_1 was 74·5° F. at $h_1 = 32''$ Hg.
t_2 „ 73·5° F. „ = „
and $t_1 - t_2$ appeared to be proportional to h_1.

The room temperature was 70·5° F. $\frac{a_2}{a_1} = 3{\cdot}3122$.

To secure great precision in the development of the final quantities, it is desirable to deal with the formula (a) piecemeal, because obviously this not only keeps one's arithmetic from straying, but it eliminates distortions arising from the omission of decimal places beyond the sixth, and imperfections in the chart-ruling (which are sometimes rather troublesome).

The ratio $\sqrt{\frac{h_2}{h_1}}$, Fig. 3 (page 981), is an important one, for although it does not appear in the thermodynamic expression, it is nevertheless the chief factor of its limit. The limit of $\frac{(2)}{(1)}$ is unity, when the thermodynamic merges into the hydraulic. The limit of $\frac{(2)^{\frac{1}{x}}-1}{(1)^{\frac{1}{x}}-1}$ is not unity but $\frac{h_2}{h_1}$. The limit of (a) (b) is limit $\frac{a_2}{a_1}$ (b) $\sqrt{\frac{h_2}{h_1}}$, and the importance of this limit will appear directly. Very great care was therefore exercised in obtaining the tangent to the primary h_2, h_1 line at zero. A large number of low readings were taken, and as extremely small heads of water were then in use, some little irregularity was to be expected. These observations are also set out in Fig. 3, and it is thought that no objection will be made in regard to the line that has been drawn through them and to the tangent alongside.

It may be remarked here that no elaborate water or mercury gauges were used—simply plain $\frac{1}{4}$-inch glass U-tubes with rubber connexions fitted into corks in the chambers—as experience shows that their simplicity ensures reliability, whereas gauges fitted into

metallic heads, unions, cocks and things, contributing to mere prettiness, are but a snare. For very small water-readings a rather smaller tube was used, with a finely divided white card-scale inserted between the tube and its back-board, and the readings were taken between the two diamond points of light on the menisci. Some prefer paraffin or petrol to water on account of the little difficulty sometimes experienced in keeping the tube wetted, but with a frequent disturbance of the column the difficulty practically disappears. In the present experiment, as mercury had to be used for h_1 and water for h_2 for the larger readings, it was preferred to keep to water and mercury so as to have only two specific gravities to deal with; and for these two media the physical data are probably more complete and precise than for any others.

The tangent at zero gives the limit value of $\frac{h_2}{h_1} = 1{\cdot}243$ or $0{\cdot}0916$, $\frac{\text{Hg}}{\text{Hg}}$, this value being independent of the value of γ, the effect of which vanishes at the limit. This value of $\frac{h_2}{h_1}$ can be checked very effectively by the $\sqrt{\frac{h_2}{h_1}}$, h_1 curve, Fig. 3, limit $\sqrt{\frac{h_2}{h_1}}$ being $0{\cdot}30265$. It will be found that an exceedingly small displacement of the tangent line from that drawn gives obviously impossible values of limit $\sqrt{\frac{h_2}{h_1}}$. For instance, $1{\cdot}24$ instead of $1{\cdot}243$ gives $0{\cdot}3021$, which is impossible because the curve would have a double inflexion at a place where there is no ground for such a thing (as there might be near the critical drop).

Three arbitrary values of γ give the dependent values shown in the following Table. These arbitrary values may all be impossible, but they are useful to check the arithmetic, to observe the effect of the variation, and to permit the analysis being independent of the true value of γ. It is more than unfortunate that, for every change of the physical constants, the current coefficients of discharge require changing. This disability should therefore not be forgotten when making comparisons. The use of

the three arbitrary values of γ in the present case will help to overcome the difficulty.

If $\frac{\gamma-1}{\gamma}=$	0·26	0·29	0·31	latest accepted value 0·28673
then $\gamma=$	1·35135	1·40845	1·44927	1·402
Critical $\frac{p_2}{p_1}=$	0·536625	0·5271	0·520128	0·52795

Now the $\frac{c_1}{c_2}$ lines, Fig. 4,* may be regarded as the coefficient of discharge of nozzle 1 if the coefficient of 2 is unity throughout;

* A warning is necessary to the unwary that the curves of Figs. 4 and 7 with these various values of γ are *not* those pertaining to *various gases* with the corresponding index. The range of values adopted is merely conventional, for there is only one true curve somewhere in the middle which represents the quality of air actually experimented with. But the range has also the useful purpose that should future research disclose that the index for pure air is not 1·402, but, say (to exaggerate), 1·38, the true line in Figs. 4 and 7 under the cult of the same thermodynamic theory is the intrapolation corresponding to 1·38, which intrapolation is simple compared with re-calculating the whole analysis. Now, having determined the credible line for air (the culminating line representing the coefficient of discharge), the difficult question arises—what is the coefficient of discharge for a given $\frac{p_2}{p_1}$, with some other gas which has a different index, and consequently a different critical point? The only reasonable answer appears to be that the coefficient is the same, alternatively (1) at the critical point or theoretical maximum discharge, or (2) at the point of actual maximum discharge. Practically the alternatives are almost equivalent. Applying the answer by way of illustration to the data of Fig. 4, suppose line *b*′BE happens to be the credible coefficient of discharge (multiplied by constant K) for air, the index for which is 1·408, and suppose that the credible line for a gas having an index 1·35 is required; from what has been said above it will be seen that the required line is not *a*′AE, but is the line *b*′BE contracted, lazy-tongs fashion, towards the origin, so that point B lies on the ordinate through A.

and the $\frac{c_2}{c_1}$ lines as the coefficient of 2 if that of 1 is unity throughout. The problem, then, is from these to construct common curves so as to give the coefficient of the nozzles (both being of the same shape, it will be remembered) referred to any arbitrary level. This is not at all difficult geometrically, and the starting-point may be anywhere. A convenient point is the theoretical point of maximum discharge. So, starting at the three points A, B, C, Fig. 4, observe first that the 0·26 line must pass through points A, a', a''.

The abscissæ for a', a'' and other sequential points are determined from curves of $\frac{p_2}{p_1}1$, $\frac{p_2}{p_1}2$, elaborated in various forms (not shown).

Thus for $\frac{p_2}{p_1}1 = 0{\cdot}5366, \frac{p_2}{p_1}2 = 0{\cdot}9115$

and for $\frac{p_2}{p_1}1 = 0{\cdot}9115, \frac{p_2}{p_1}2 = 0{\cdot}99105.$

The ordinate for point a'' equals $a'd$, as in Fig. 4 construction (overleaf), and a'' lies also on line $\frac{c_2}{c_1}$.

Other points are derived in the following way: for instance, at $\frac{p_2}{p_1}1$ the distance $rs = r's'$ at $\frac{p_2}{p_1}2$, this distance being ascertained by trial so that all points lie on a consistent line. The construction will be found to be very sensitive to an inaccuracy, and the resultant lines are obtained with great precision, as referred to the prime data. These lines Aa, Bb, Cc, are thus proportional to the coefficient of discharge for this particular shape of nozzle, for any comprehensive ratio $\frac{p_2}{p_1}$ and the assumed γ. It only remains to determine the constant multiplier K, which, if somewhere about unity, means that the curves practically go up or down bodily, as the case may be, for them to represent then the absolute coefficient of discharge referred to the adiabatic standard.

At this stage the relative coefficient lines Aa, Bb, Cc, may be left as they are, while their limits and another set of experiments are discussed.

The Upper Limit in the Vicinity of Maximum Discharge.—Within the limits of the above experiments the curves are rising rather steeply, which feature it will be observed agrees with the Rateau and Hirn curves in Fig. 1 (page 980). Now, beyond the critical point the thermodynamic formula is like the air itself—it cannot impose the terminal pressure conditions upon the nozzle at its outlet plane, so that really in the curves beyond this point a fictitious value of $\frac{a_2}{a_1}$ was being used, the true a_1 being larger as indicated in Fig. 5 by b.

Construction of Fig. 4 (pages 986–7).

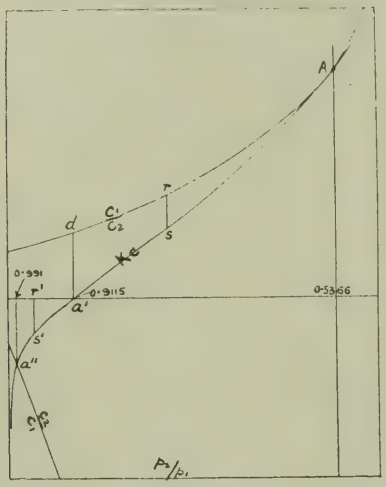


FIG. 5.

Referring to Fig. 4 (pages 986–7), the axis of X represents the ideal coefficient of discharge from the unity origin up to the critical point—and then what happens to it? If in imagination the terminal pressure conditions be forced upon the nozzle, the result is a hypothetical stream as shaded in Fig. 5, and an equivalent throat area a'_1 instead of a_1. And if the thermodynamic expression be applied to a_1 as the actual outlet area, the theoretical discharge, as is well known, falls away to zero for $\frac{p_2}{p_1} = 0$; and this is equivalent to reducing the throat area from a_1 through a'_1 to zero.

The ratio $\frac{a'_1}{a_1}$ therefore represents the theoretical coefficient as well as the discharge for the terminal pressure conditions thus imposed on the nozzle at a_1.

$\frac{a'_1}{a_1}$ are set out by curves D.

If now the actual coefficients of discharge A*a*, B*b*, C*c* (it is immaterial for the moment whether they are relative or absolute) be multiplied by the theoretical discharge D, the actual discharge-lines E are obtained. The middle line, which is close to that for the probable value of γ, seems likely to follow the dotted extrapolation E', and so the experimental fact emerges that the discharge is for some purposes practically constant, but, clearly, not quite. On this point of approximate constancy further remarks are necessary. If the super-critical theoretical ratio of discharge to critical discharge be drawn as at F, and then multiplied by the relative coefficient of discharge A*a*, B*b*, C*c*, the actual discharge G is seen to be perfectly continuous with E.

This is the line (subject to the constant K of relativity) corresponding to the principal line of the Rateau diagrams previously referred to.

These experiments, and the above interpretation of them, confirm that the point of actual maximum discharge does not occur at the theoretical point, but it places the maximum at a lower value of $\frac{p_2}{p_1}$ than is commonly understood. The vertical scale of Fig. 4, however, is very large. Drawn to a more ordinary scale of one-tenth (also in Fig. 4, dotted line), this characteristic for the line when $\gamma = 1{\cdot}402$ is not so pronounced; and apparently the hump between, say, $0{\cdot}52$ and $0{\cdot}45$ is well within the limits of accuracy claimed by predecessors, and therefore possibly may have been obscured.

The Limit at Zero Discharge.—If a curve (not reproduced) of $\frac{p_2}{p_1}2$ be plotted against $\frac{p_2}{p_1}1$ it will be observed that when point (1) is $0{\cdot}99$, point (2) is very approximately $0{\cdot}999$, and $0{\cdot}999$ gives nearly

0·9999, and so on. Further, close to the limit the decrement of the coefficient for each approximate tenth step is the limit of $\left\{(b)\sqrt{\frac{h_2}{h_1}} - 1\right\}$ or 0·00248679. Now, it will be a great convenience to find the decrement for exact tenth steps. (The experimental approximation to the tenth step is fortuitous, and depends on $\frac{a_2}{a_1}$) The process of getting the exact tenth decrement involves many figures, so it cannot be given in detail. The decrement is constant up to the sixth place of decimals for all values of $\frac{p_2}{p_1}$ greater than 0·9999. The decrement for ultra-tenth steps works out to 0·00247246, with the following result:—

Arbitrary $\frac{\gamma - 1}{\gamma}$	$\frac{p_2}{p_1}$	Kc
0·26	0·9999 ... insert .... 5 (n nines)	0·986184—0·00247246n
0·29		0·988278— do.
0·31		0·989906— do.

Thus, if K is known, the coefficient for any minute drop of pressure can be ascertained to within the sixth place of decimals for the particular shape of nozzle under discussion.

Taking $\gamma = 1{\cdot}401812$ for the mixture actually experimented with (page 1000)—

$$Kc = 0{\cdot}988064 - 0{\cdot}00247246n \quad . \quad . \quad (c)$$

The value 0·988064 in this expression holds so long as γ for pure air is 1·402. If it transpire one day that it is not 1·402, then the corresponding curve must be intrapolated from the four curves drawn for geometrically accessible pressure ratios, and arithmetically for very high values from the bottom figures in Table 3, columns 5 and 6 (page 1016). It does not hold directly for steam or any other gas where the index is not 1·401812, for the simple reason that the position of the critical point differs. To

correct for this factor after selecting the proper air-mixture curve on the diagrams, the application of the "lazy tongs" to that curve between the theoretical critical point and unity ratio, will most probably give the nearest possible approximation to the truth. (*See* foot-note on page 990.)

The same remarks apply to the H.T.P. (page 1001).

The refinement in the value and effect of γ is given more for the sake of consistency. As a matter of fact the difference between the coefficient curves for 1·402 and 1·40181 is hardly appreciable on a very large scale chart. In short, ordinary humidity is quite a negligible factor.

For further remarks on n, *see* page 999 after consideration of the next experiment with the "hole-in-a-thin-plate."

Discussion of the Sub-critical Coefficient.—In regard to Dr. Morley's deduction (whose experiments are the latest extant on the subject) that the sub-critical coefficients are constants for all sorts of nozzle except the hole-in-a-thin-plate, there are several considerations which discount it. In the first place he does not claim an accuracy within 1 to $2\frac{1}{2}$ per cent, which is rather a wide margin for the present point of view. Moreover, it will possibly have been noticed that a very small divergence of his (log p, time) curves from the straight makes quite a large variation in the coefficient, and on this account alone it does seem a little weak to declare absolute uniformity in the coefficient from a line which is certainly very approximately straight over a long range, but still only approximately so. But a most potent, though intuitive, argument against the existence of a uniform sub-critical coefficient is the palpable improbability of it as a law in the face of a consistent variation of the super-critical coefficient where the stream-waves are nothing like so violent, and in the face of the fact that straight-line laws are very few and far between, if they exist at all, in nature; there may be, and are, proximates, but that is about as far as one is justified in postulating. It will be remembered that Stodola's experiments show the waves to be extremely violent and various, conditions which are hardly the complement of a uniform

coefficient. Further, by converse argument, it is extremely remarkable if his (Morley's) so-called H.T.P. (this label is the Author's; Morley calls it "an orifice in a thin flat disc") should be the only exception, for one reason because the coefficient is very sensitive to an appreciable thickness of plate, rising roughly from 0·65 to 0·9 (for $\frac{p_2}{p_1}$ = about 0·975) as the thickness increases from zero to about two diameters, and then falling again as the nozzle becomes a pipe. Not only this, but it apparently rises and falls in a series of waves and not in one wave, which might be surmised from the observed variation in the pressure waves in the emergent stream. (This fact emerges from other experiments by the Author not here detailed.) These phenomena are fatal to a uniform coefficient, just as their analogies in a hundred and one other and more tangible operations are known to be. The coefficient is also sensitive to a bevel, as Morley himself shows. See also Fig. 6 (page 987) and context (page 1001). The point of this is that his H.T.P. appears rather to belong to the same order of nozzle as his varieties than to the true H.T.P., and might reasonably be expected to share some of their idiosyncracies, one of which is the alleged constant sub-critical coefficient.

On all these accounts the Author is of opinion that closer research in the sub-critical range will reveal a disturbance of Morley's uniform coefficient for every nozzle to at least some three or four digits in the second place of decimals. Whether the general level of his coefficients is accurate or not is another matter.

The Author's gauges (he will not tolerate dial-gauges for the purpose) being laid out for the super-critical range, were not able to explore lower than 0·47, and therefore the criticism of the sub-critical range is necessarily not quite complete. But there is one other point indicating a variable coefficient. The h_2, h_1 curve, Fig. 3 (page 981), must continue on the right side of its tangent at $h_1 = 38''$, and this tangent (outside the figure reproduced) yields the extensions H, H′ of curves $\frac{c_1}{c_2}$ and Kc respectively, Fig. 4 (pages 986–7).

If the Kc extension be multiplied by curve D the fall is very

steep indeed. Again, in Fig. 3 produced, *there is no regular curve between this tangent and any possible or probable locus on the right of the tangent which will yield a uniform sub-critical coefficient.* While, therefore, the coefficient must lie between H′ and some steeply rising curve to the left of *a*, *b*, *c*, there is no regular h_2, h_1 curve which will yield the exact complement of curve D and thence a uniform coefficient. This is a little involved, but it seems good circumstantial evidence. An inspection of the elements of the coefficients and their values leads pretty definitely to the curves E as drawn, down to the pressure ratio 0·43 or thereabout.

Experiment with a "Hole-in-a-thin-plate."

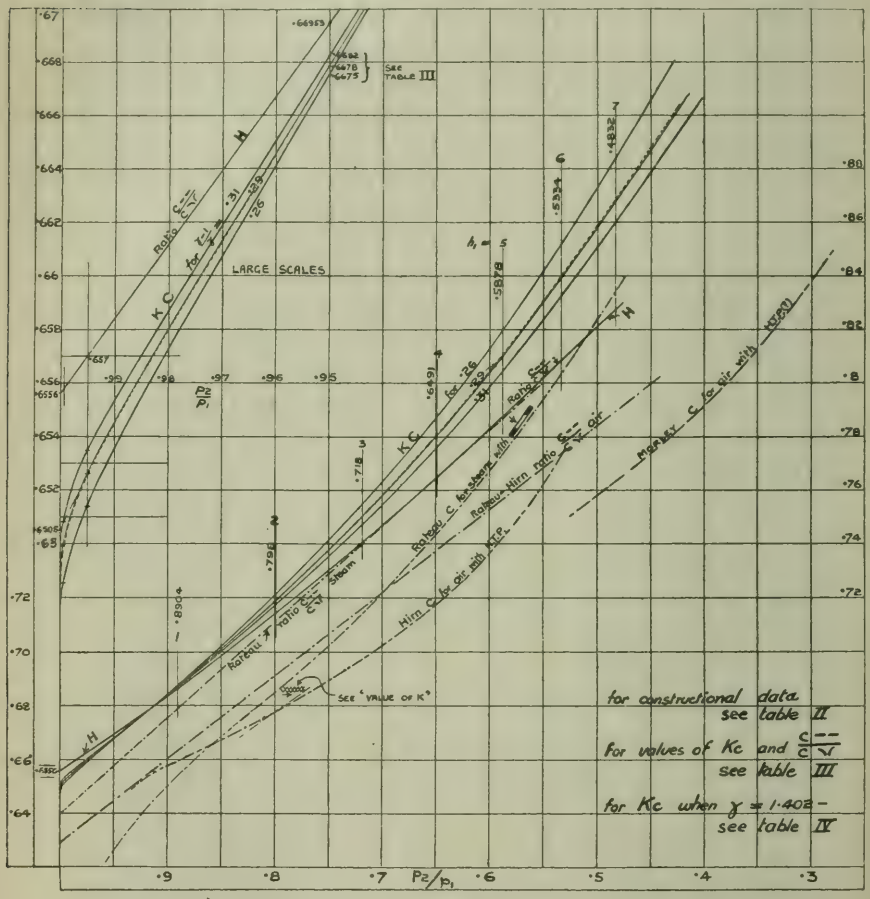
Hole-in-a-thin-plate (symbols H.T.P. and – –).—Keeping the same convergent nozzle at the inside diaphragm, and exchanging the second nozzle for a hole-in-a-thin-plate, an experiment should yield more or less directly the ratio of the coefficient of the one type to that of the other, as exemplified by the Hirn-Rateau line, which the latter investigator concludes to be straight over the super-critical range.

The diameter of the plate hole was 0·2333 inch, and the thickness of the plate 0·0049; thus $\frac{d}{t} = 47{\cdot}7$. It will be recalled that the convergent nozzle inside was 0·25975 inch diameter. Thus the ratio $\frac{a_2}{a_1} = 0{\cdot}80671$.

The relative diameters permitted a small ratio $\frac{p_2}{p_1}1$ for a large ratio $\frac{p_2}{p_1}2$. Fig. 3 gives the primary h_2, h_1 line from the experimental points, and from this line Table 2 (pages 1014–5) has been built.

The $\frac{c_2}{c_1}$ of this Table is not the required $\frac{c - -}{c \gamma}$ because the pressure ratio is not the same for both. To obtain this, another Table 3 (page 1016) must be built. In this Table column 5 is the coefficient of discharge of the H.T.P., subject to multiplication by the same unknown constant K as for the converging nozzle. Column 7 gives the required ratio of the coefficients, which values are

FIG. 7.—*Data for Hole-in-a-thin-plate—also Ratio of its Coefficient to that of Converging Nozzle.*


LARGE SCALES
SEE TABLE III
Ratio C/√H for 1·31 1·29 1·26
K C √H
Ratio C/√H shown
Rothert
Hirn C for air with K.E.
Marriotte C for air with K.E. lost
Rateau Hirn ratio C/√H for air
Bolgeo C for steam with K.E. lost
Ratio C/√H for 1·28 1·30 1·32
for constructional data see table II
for values of Kc and C/√H see table III
for Kc when γ = 1·402 — see table IV
SEE 'VALUE OF K'
P2/P1

absolute and not subject to the constant. This is set out in curve H, Fig. 7.

In column 7 for the three arbitrary values of γ there is a slight discrepancy, hardly perceptible at the high ratios, and about 0·2 per cent near the critical, but of course there should be absolute identity. These discrepancies arise solely from the little imperfections in scaling and from cumulative arithmetical errors. The fact that the three lines collect together with such a small discrepancy is nevertheless a check on the general accuracy of the whole process, for it is not quite the same thing as the popular addition and subtraction puzzle, because all values of the Kc had to be taken from the curves, which were not directly calculated.

Limit Values of the H.T.P. Coefficient near Zero Discharge.—The data lead as before to point $\frac{p_2}{p_1} = 0{\cdot}99995$, where the coefficient for the three values of γ is 0·646935, 0·648225, 0·649196, and where the decrement becomes constant up to the sixth decimal place. This mean decrement is 0·6556 of 0·00247246 = 0·00162094.

So, for any higher tenth value of $\frac{p_2}{p_1}$ the coefficient is given by

Arbitrary $\frac{\gamma - 1}{\gamma}$	$\frac{p_2}{p_1}$	Kc
0·26	0·9999...insert....5 (n nines)	0·646935—0·0016209n
0·29		0·648225— do.
0·31		0·649196— do.

For $\gamma = 1{\cdot}4018$ for the mixture actually experimented with

$$Kc = 0{\cdot}648113—0{\cdot}0016209n \quad . \quad . \quad . \quad (d)$$

A curious little point arises from this. If the limit of c is zero, as seemingly it must be, put $c = 0$ and K about 0·957 (*see* page 1002), then $n = 382$ ($\pm$ 6 for "even chance" error).

That is, $\frac{p_2}{p_1}$ limit $= 5 \times 10^{-387} \times 14{\cdot}7$ lb. sq. in.

and v limit $= 10^{-190}$ ft. sec.

Presumably this limit pressure is a function of a viscosity. The unit of gaseous viscosity is of the order 10^{-4} (c.g.s.), and it is rather difficult satisfactorily to connect the quantities. Possibly the limit thickness of nozzle edge, which is of molecular dimensions, provides the necessary key. The Author hardly feels competent to explore this region of molecular physics, so he leaves it here to the physicists.

Humidity.—As previously stated, the humidity was practically 40 per cent constant throughout.

The present accepted values of the constants for air—

$$Cp = 0{\cdot}2417.$$
$$Cv = 0{\cdot}17239.$$
$$\gamma = 1{\cdot}402.$$

For water vapour at 25° C—

$$Cp = 0{\cdot}4669 - 0{\cdot}0000168 \times 25 + 0{\cdot}000000044 \times 625 = 0{\cdot}4665.$$
$$Cv = 0{\cdot}34.$$
$$\gamma = 1{\cdot}37.$$

For the mixture—

the moisture, $w = 0{\cdot}000468$ lb. per cubic foot.

air, $a = 0{\cdot}073$ „ „ approx. enough.

$$Cp = 0{\cdot}2417 + 0{\cdot}233\frac{w}{a} = 0{\cdot}24319.$$

$$Cv = 0{\cdot}17239 + 0{\cdot}17\frac{w}{a} = 0{\cdot}17348.$$

$$\gamma = 1{\cdot}401812, \quad \frac{\gamma - 1}{\gamma} = 0{\cdot}286637.$$

This, then, is the value of γ for the actual stuff experimented with, and the true curves are those involving this value—at any rate until proved otherwise. These curves are drawn dotted in Figs. 4 and 7, and are tabulated in Table 4 (page 1017), because it is impossible to reproduce in a small plate the fine pencil lines of the large original diagrams.

Critical Remarks on the Hole-in-a-thin-plate Results.—It will be observed that the curve of the ratio of the coefficient of the H.T.P. to that of the convergent nozzle is not quite straight, that it has an origin at 0·6556 (possible but unlikely variations, 0·6557 to 0·65555), that it does not agree within $3\frac{1}{2}$ per cent of the Hirn air-line, and that it agrees precisely with the Rateau steam-line at below 0·7. There seems to be no reason why the *ratio* should be different with different gases or even liquids, so it is but reasonable to conclude that the comparatively large discrepancy between the Hirn and Rateau lines arises in some errors in their experimental observations. Of the two, the Rateau with steam, being at a later date and determined from the actual condensate, would naturally tend to be the more credible. So that, on the whole, the Author ventures to consider the evidence in favour of the new line as a refinement. But there is a further and rather important consideration. Rateau's hole-in-a-thin-plate is certainly not that article even approximately, not even so approximately as Morley's. The plate is not only substantially thick, being $\frac{1}{10}$ of the diameter, but *the edge is bevelled* at about 45°. Now, the latter factor has an enormous influence on the discharge where the thickness is equal to the diameter, as shown by some other experiments by the Author, and quite a substantial influence when the thickness is only about $\frac{d}{10}$ (his drawing is not dimensioned), as proved by Morley* whether one agrees with his coefficients as absolute or not. The effect of bevelling when the thickness is equal to a diameter, and when the pressure ratio is about 0·975, is shown in Fig. 6 (page 987). (These curves have not been rigorously dealt with as in the above experiments, and may therefore require some little refining to make them quite absolute. K is taken at 0·9551 as on page 1003.) This evidence, it is considered, is sufficient to discount the Rateau results near the origin, and to leave ground for the acceptance of the Author's line.

The Value of K.—The constant K for converting the relative into absolute coefficients will now be considered. As mentioned in

* Proc. I.Mech.E., 1912 (page 78).

the introduction, precise information is wanting, but what little evidence is extant may be examined, weak though the examination may be from a scientific point of view. Hirn states that the coefficient of the H.T.P. at very small heads is 0·633; but as it has been shown that at very small heads the coefficient is in a state of very rapid flux, this figure is almost meaningless. If it be taken at the pseudo-origin (*see* Fig. 7, page 998), then approximately—

$$K = \frac{0\cdot633}{0\cdot6505} = 0\cdot9731;$$

if taken at, say, 0·995 ($2\frac{1}{2}$ inches water) just before the curve tails down steeply—

$$K = \frac{0\cdot633}{0\cdot6525} = 0\cdot97235,$$

both of which values are decidedly high.

Chandler's figures with coal gas* yield for the range $2\frac{1}{2}$ inches to 4 inches water ($\frac{p_2}{p_1} = 0\cdot992$ mean)—

$$K = \frac{0\cdot6302}{0\cdot65785} = 0\cdot957969.$$

Referring to Fig. 1 (page 980) for the convergent nozzle, Rateau and Hirn agree at $\frac{p_2}{p_1} = 0\cdot7$, and for the H.T.P., Fig. 7, they agree at 0·855; but here one is for air and the other for steam, and the lazy tongs may reasonably be applied to the steam-line to allow for the difference in the critical points and so bring them to a common air basis. Applying this process †—

For)(they cross at 0·66, giving $c = 0\cdot9744$,

and for — — „ „ „ 0·80 „ $c = 0\cdot6775$.

So for)($K = \frac{0\cdot9744}{1\cdot0203}$ (Fig. 4) $= 0\cdot955$,

for — — $K = \frac{0\cdot6775}{0\cdot7192}$ (Fig. 7) $= 0\cdot95402$.

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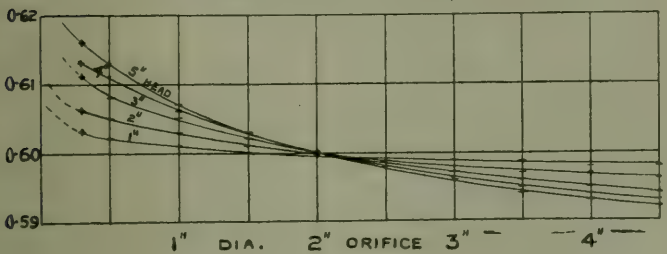
* *Gas World*, Vol. lii, page 153.

† Note (*post-discussion*).—These values remain unaltered by Mr. Hodgson's more rational method of comparison.—A. J.

There are thus at least four chances that K lies between these two values, to one chance given by any one-sided spot. Introducing Chandler's value 0·95797 obtained with a H.T.P., the chances are that K lies between about 0·9545 and 0·95797, and is therefore plausibly about 0·9551 (subject to the fluctuating estimates of the physical constants).

While there are many other researches which might be referred to, unfortunately they yield figures surrounded by even more mist than those above; so it is not proposed to discuss them. But the Author feels bound to make some reference to the experimental results of Professor Durley,* because at first glance, and in one sense, they strike at the root of the substance of this Paper. And

FIG. 8.—*Durley's Coefficients of Discharge for plain orifices in plate 0·057 inch thick, with small air pressures.*
(Trans. A.S.M.E., vol. xxvii.)



not only so, but if it be true that "size" is an appreciable factor in the coefficient of nozzles, he foresees a practically impregnable obstruction in the path of the researches of the Steam-Nozzles Committee which are already launched. The Durley experiments also being modern, and having the merit of embracing a series, seem to call for some comparative notice.

These results are remarkable for indicating a substantial variation in the coefficient of discharge of a plain hole-in-a-plate with the size of the hole, which in that case varied from $\frac{5}{16}$ inch to $4\frac{1}{2}$ inches diameter. The plate, however, was of constant thickness, 0·057 inch for all sizes, so the thickness varied inversely with the size.

* Trans. A.S.M.E., xxvii.

Professor Durley rightly points out that his coefficients only apply to the nozzles experimented with (and of course the same proviso applies to the Author's and every other case), so the observed variation in the coefficient might possibly be traced to the variation of relative thickness. But the plotted Durley figures (size against c for constant heads, Fig. 8) do not have a common asymptotic coefficient for infinite thinness, the value varying from about 0·6 for zero head to 0·588 for ratio 0·9876. Below $\frac{d}{t}$ = about 38 his coefficients increase with the pressure, and vice versa, and at this value the coefficient is nearly a constant 0·5995 for every condition. That the coefficient for limit thinness should vary with the size is inconceivable. There is no *a priori* reason why the coefficient should be different for an orifice a mile or an inch diameter, *given a similar environment*, for the smallest nozzle it is possible to make is still very large compared with molecular dimensions; and it seems necessary to reiterate that fluid motion is purely a molecular phenomenon. So possibly a key to the anomalies may be found in the above italics.

But in one aspect the Durley results are broadly consonant with otherwise known facts—the coefficient increases with the thickness of the plate; and one is quite prepared to accept the result that there is no such practical affair as a true "hole-in-a-thin-plate"; it is therefore necessary always to state the diameter-to-thickness ratio. Moreover, it has been pointed out on page 996 that the coefficient apparently increases in waves up to about two diameters thick, so that a reference to any H.T.P. experiments is liable to be a little misplaced. Probably the coefficient of a H.T.P. of above 25 or 30/1 is reasonably free from $\frac{d}{t}$ flux, but the reference must naturally be treated on its merits.

Referring to Fig. 8 (page 1003) and taking coefficients for $\frac{d}{t}$ = 47·7 as in the Author's H.T.P., K works out to 0·91065 for 5-inch press, and 0·91978 for 1 inch, the average being 0·9152. These values all seem much too low (they make $)(c_{max} = 0·96$, which more than discounts the "excess" discharge as observed by Rateau); for there is a considerable weight of evidence tending to an

approximate value of 0·62 (yielding K about 0·95) for small heads with "sharp-edged orifices," although, as has already been pointed out, there is so much sensitiveness to what is before and behind the so-called sharp edge, that it is impossible to identify any two extant figures in the third place or even the second place of decimals, to say nothing of the prevalent adoption of some more or less generous approximation in the theoretical datum. But further as to the variation of the coefficient with the size beyond the acceptable latitude for thickness and for a possible special environment in the Durley experiments, some strength is given to the adverse criticism, because it would be found to be practically impossible to construct a consistent resultant curve Kc from the $\frac{c_1}{c_2}$ and $\frac{c_2}{c_1}$ as in Fig. 4 if such a variation in the coefficient existed. As an extreme example it may be tried in vain with the figures of Table 2 (pages 1014–15), where the two nozzles have a markedly different coefficient and characteristic.

Morley, at the critical pressure, yields K = 0·888 with his plain 0·196-inch orifice, and the flat side facing stream; but as the thickness and bevel are not dimensioned (the thickness appears from the sketch * to be about $\frac{1}{10}d$), and the claim for accuracy is only within 1 to $2\frac{1}{2}$ per cent; also, as the value is empirically wrong for a H.T.P., the reference does not assist, in fact it adds an element of unfortunate and still greater discord. The almost hopeless discordance shown to exist between the results of the Author's predecessors renders it rather unprofitable to search for a precise value of K among them, especially as it is outside the spirit of this Paper to deal with broad approximations. For the present, then, K may be placed at what has been called a plausible value of 0·9551, and the section is concluded with the presentation of Fig. 9, giving the absolute coefficients of the convergent nozzle and "hole-in-a-thin-plate" based on this value. It will be observed that this value of K places the excess discharge at the maximum at 0·203 per cent, which is a trifle less than that adduced by Rateau from his own steam experiments, and those of Hirn for air.

* From later information $\frac{1}{7·7}$.

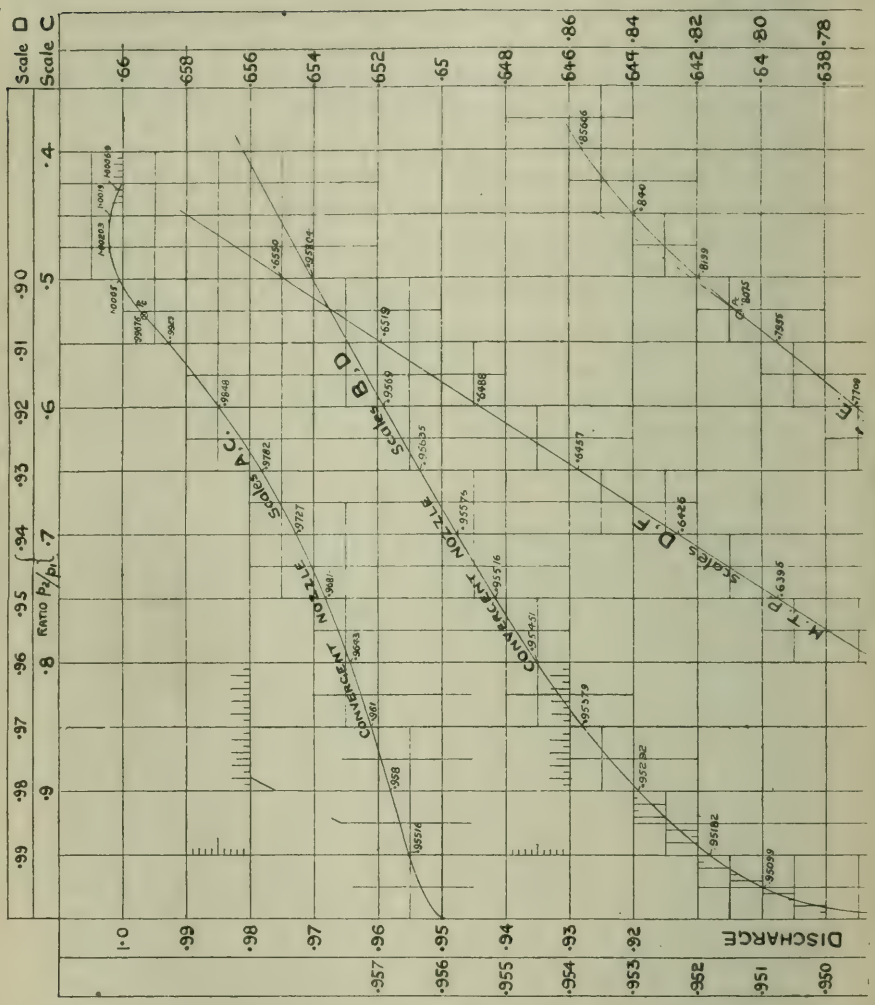
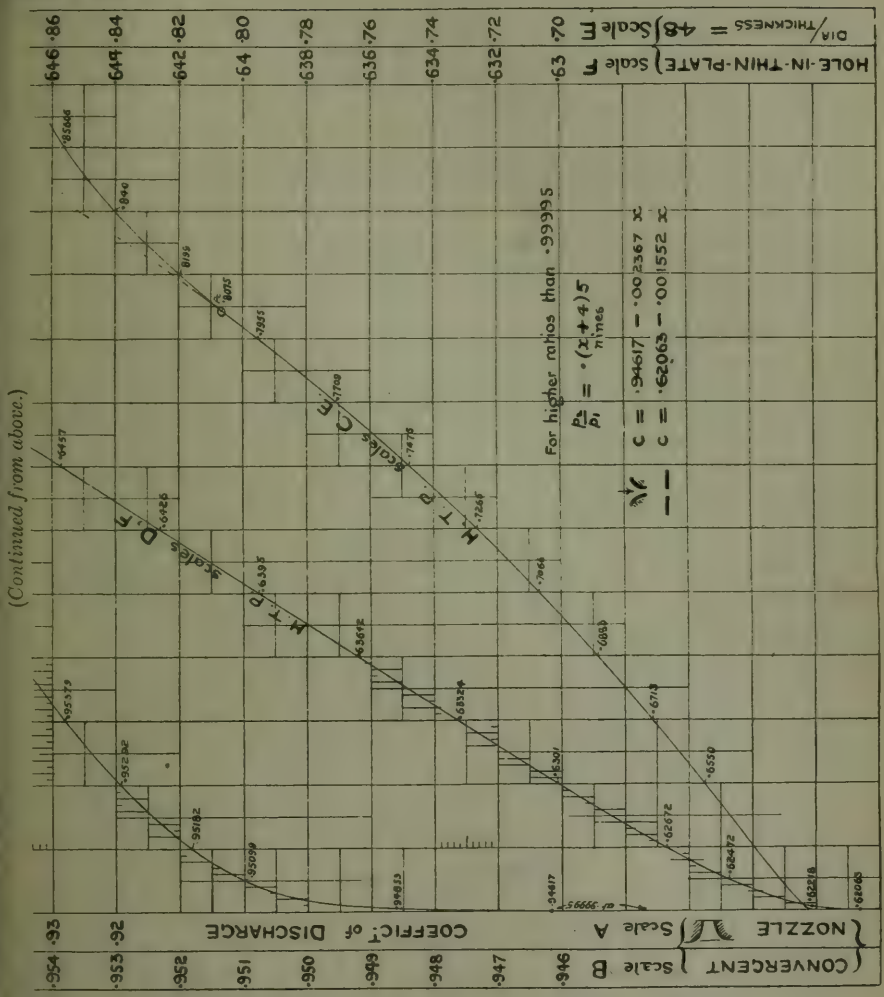


FIG. 9.—*Coefficients of Discharge of Converging Nozzle and Hole-in-a-thin-plate.*
(Tentative—sec (4) page 1010.)

By revision since drawn, the value of K here embodied is better 0·9551 than

Practically a reduction of 0·0025 (J) and 0·0015

Table 4 with K = 0·9576.



0·9576; the coefficient should therefore be multiplied by 0·9975 or $\frac{1}{1·00249}$.

(– –) will suffice; for example, for 0·6457 read 0·6442.

In regard to the tentative adoption of Fig. 9 coefficients for *any* curved convergent nozzle of approximately the same form, it will be noted in Fig. 6 (page 987) that for a conical nozzle the coefficient is practically constant for an included angle of 20° to 30°. It may therefore be inferred tentatively that a conoidal nozzle would also possess a similarly constant coefficient over a corresponding variation of form.

Notes as to Accuracy.—The nature of the primary h_2, h_1 data does not permit an appreciable observational error with ordinary precautions. The curve must obviously be regular both above and below the critical point, although there may be an inflexion somewhere thereat.

The observations do not depend upon the perfection of any mechanism other than tight joints and true scales. It is assumed that the mercury, water and air used were within the tolerable degrees of purity demanded by the physical tables.

The Author is not prepared to admit a static observational error of any one point of more than $\frac{1}{20}$ inch; and at least ten reset readings were taken for each stationary point.

Now, in the convergent nozzle and combination experiments respectively, $\frac{1}{20}$ inch in h_2 (water) affects the final coefficient 0·0005 and 0·00025 at $h_1 = 30$ inches and 7 inches respectively; and as the theory of probability indicates even chances that the curve error does not exceed about 2 per cent of the maximum spot error, it is even chances that the error in the coefficient does not exceed 0·000010 and 0·000005 respectively.

Combining the physical with the geometrical error, the result is that there are about even chances the ± error does exceed—

(a) at the high-pressure limit, $\frac{p_2}{p_1}$ = about 0·47

Nozzle	M	— —
even chance error	0·00011	0·000105

(*b*) at the origin

even chance error	0·0001	0·0001

Remote places in the finals, while given for completeness, may therefore be ignored without following the somewhat deplorable but usually compulsory practice of starting with fastidious precision, both theoretical and practical, and ending with spacious approximations.

A Note on the Use of the Series Apparatus.—For the extraction of a coefficient, given a datum nozzle, the employment of the cumbersome arithmetic of the thermodynamic expressions is somewhat abbreviated by the elimination of common factors in the ratio $\frac{c_1}{c_2}$. But calculations are further facilitated by constructing a permanent curve of the logarithms of $\left(\frac{p_1}{p_2}\right)^x$ $\left\{\left(\frac{p_1}{p_2}\right)^x - 1\right\}$ to an adequately large scale. These values may be ascertained from Table 1 for the three arbitrary values of γ. For the credible value of γ the curve may be intrapolated (noting that for $\gamma = 1{\cdot}402$ $\left(\frac{\gamma-1}{\gamma} = 0{\cdot}28673\right)$ it lies very exactly at one-tenth of the distance between the 0·29 and 0·26 lines) or re-calculated as a permanent basis. To follow the extraction into very high ratios of $\frac{p_2}{p_1}$ may be a little involved according to circumstances, but no doubt in the majority of cases now remaining where the nozzles will be of the convergo-divergent type and have particular reference to turbine requirements, this pursuit will be unnecessary.

Conclusion.—To sum up briefly, the Author ventures to think that he has shown :—

(1) The comparative value of the series apparatus to be considerable generally, and especially at the higher ratios where the coefficient is extremely sensitive to the ratio.

(2) An intrinsic accuracy in the apparatus not present in the ordinary reservoir type. (The reservoir apparatus is only with great difficulty applicable to small ratios, because it is difficult to gauge the primary differential curve at low pressure drops, the curve not being sufficiently self-checking.)

(3) The need for some one precise determination of the absolute coefficient for the nearest possible approximation, either to a reasonably true hole-in-a-thin-plate, or a conoidal convergent nozzle for preference. It is suggested that a suitable spot is at about 0·91, where the coefficient is fairly constant and practically independent of the value of γ.

And it is submitted that—

(4) A datum curve (Figs. 4, 7, dotted lines K*c*) with tabular extension (Table 3, columns 5 and 6) and formulæ (c) and (d) accurate to at least the fourth place of decimals has been provided for the application of a true datum spot for the convergent nozzle and hole-in-a-thin-plate respectively which should be ascertained by some careful research in the future by someone possessing the suitable apparatus, so as to enable the above-mentioned particulars to assume absolute values (more or less approximating the curves in Fig. 9 which provide a tentative interregnum).

He would also suggest that if Dr. Morley's or similar apparatus be used, the extremely bad pipe-and-cock arrangement leading to the nozzle be discarded for a large full-way valve, not less than twenty diameters of nozzle, bolted directly on to the bottom, with the nozzle plate also bolted directly on to the flange of the valve. Also that mercury columns be used instead of gauges.

The Paper is illustrated by 9 Figs. in the letterpress.

TABLES 1–4.

TABLE 1.—

h''_1	h''_2		$\sqrt{\frac{h_2}{h_1}}$	Bar.	$\frac{p_2}{p_1}1$	$\frac{p_1}{p_2}1$	$\frac{p_2}{p_1}2$	$\frac{p_1}{p_2}2$
	H_2O	Hg.	Hg./Hg.					
38	55·55	4·0935	0·3282	29·53	0·4694	2·130	0·8780	1·1386
36	52·15	3·8430	0·3267	,,	0·4810	2·097	0·8849	1·1300
32	45·45	3·349	0·3235	29·57	0·5069	1·9725	0·8981	1·1134
30	42·16	3·1068	0·3218	,,	0·5213	1·9181	0·9049	1·1050
28	38·90	2·866	0·3200	,,	0·53665	1·8633	0·9117	1·0967
26	35·75	2·6374	0·3184	,,	0·55334	1·8072	0·9180	1·0893
20	26·88	1·9808	0·31415	,,	0·6120	1·6340	0·9372	1·0670
15	19·70	1·4517	0·31093	,,	0·6740	1·4837	0·9532	1·0491
10	12·80	0·9491	0·30807	,,	0·7520	1·3298	0·9689	1·0321
5	6·34	0·4672	0·30530	,,	0·8570	1·1668	0·9842	1·0160
4	5·08	0·3743	0·30480	,,	0·882			
3	3·8	0·2800	0·30428	,,	0·9087			
2	2·5035	0·1845	0·30375	,,	0·937			
1	1·2475	0·0919	0·30320	,,	0·967			
0			0·30265	,,				

The three values are for $x=\frac{\gamma-1}{\gamma}=0·26$, 0·29, 0·31 respectively. Logarithms purposes. The two columns provide twenty points, and intrapolations are easy

For the experiments $\rho(\text{Hg.})=13·54326$ (c.g.s.) and $(H_2O)=0·99797$, by Kaye

Convergent Nozzle.

Logarithms.							
$\sqrt{\left(\frac{p_1}{p_2}1\right)^x}\times\sqrt{\left(\frac{p_1}{p_2}1\right)^x-1}$	$\sqrt{\left(\frac{p_1}{p_2}2\right)^x}\times\sqrt{\left(\frac{p_1}{p_2}2\right)^x-1}$	$\frac{p_2}{p_1}2$	$\sqrt{\frac{\tau_1}{\tau_2}}$	(b)	$\frac{c_1}{c_2}$	$\frac{c_2}{c_1}$	Kc at $\frac{p_2}{p_1}1$
1·711180	1·275114			1·00004225	1·0668	0·93735	1·0588
742363	300094	943529	000464	1·00004352	1·0517	0·95107	1·0450
761826	318137			1·00004377	1·0420	0·95970	1·0337
702016	261474				1·0638	0·9400	1·0583
732960	290414	946894	000438		1·0488	0·9534	1·0447
752265	301593				1·0397	0·9618	1·0378
681368	232118				1·0575	0·9456	1·0562
711785	256882	953349	000390		1·0435	0·9583	1·0427
730757	272074				1·0349	0·9662	1·0337
669771	215280				1·0542	0·9485	1·0543
699943	239955	956601	000365		1·0408	0·9608	1·0408
718678	255031				1·0326	0·9682	1·0326
657436	197943				1·0510	0·9514	1·0510
687293	222537	959700	000340		1·0381	0·9633	1·0380
705869	237562				1·0302	0·9706	1·0304
643882	180100				1·0477	0·9544	1·0471
673442	204800	962700	000316		1·0353	0·9658	1·0349
691349	220383				1·0280	0·9727	1·0275
595090	118885			1·00004676	1·0375	0·9638	1·0356
623319	143117	971832	000244	1·00004721	1·0273	0·9733	1·0257
641024	158198			1·00004727	1·0212	0·9791	1·0200
539038	051941				1·0288	0·9720	1·0256
566628	076082	979184	000182		1·0207	0·9797	1·0179
583695	090982				1·0157	0·9845	1·0136
460000	2·959905			1·00004872	1·0202	0·9801	1·0155
486800	983982	986297	000121	1·00004881	1·0143	0·9858	1·0104
502560	998580			1·00004882	1·0105	0·9896	1·0076
314866	809134				1·0114	0·9887	1·0045
338859	833038	993083	000060		1·0082	0·9918	1·0030
355486	847580				1·0058	0·99414	1·0017
							Scale from Fig. 4 large scale curves.
				1·00004949	1·00248679	0·99751321	

are given to six places, which are sufficient to enable a chart to be constructed for general for other values of γ.

and Laby's tables. Hence $\frac{\rho\ (\mathrm{Hg.})}{\rho\ (\mathrm{H_2O})} = 13{\cdot}5708.$

TABLE 2.—"*Hole-in-thin-*

h''_1)(Hg.	h''_2 – – Hg.	Bar.	$\frac{p_2}{p_1}1$	$\frac{p_1}{p_2}1$ (i)	$\frac{p_2}{p_1}2$
7	31·65	29·6	0·8980	1·11428	0·4832
6	25·88	,,	0·9024	1·10814	0·5334
5	20·75	,,	0·9096	1·09930	0·5878
4	16·00	,,	0·9193	1·08771	0·6491
3	11·56	,,	0·9320	1·07288	0·7180
2	7·48	,,	0·9488	1·05393	0·7980
1	3·64	,,	0·9708	1·03006	0·8904
0					

)(Symbol for convergent nozzle.
– – ,, hole-in-a-thin-plate.

plate" with Convergent Nozzle.

$\frac{p_1}{p_2}$ 2 (2)	(b)	$\frac{c_1}{c_2}$	$\frac{c_2}{c_1}$
	1·00000208	1·1333	0·8824
2·06926	1·00000206	1·1530	0·8673
	1·00000205	1·1628	0·8599
		1·1740	0·8512
1·87432		1·1900	0·8392
		1·9950	0·8328
		1·2201	0·8196
1·70101		1·2338	0·8104
		1·2423	0·8049
		1·2691	0·7882
1·5405		1·2799	0·7813
		1·2873	0·7772
		1·3223	0·7562
1·3905		1·3307	0·7515
		1·3364	0·7482
		1·3800	0·7240
1·2527		1·3860	0·7211
		1·3893	0·7190
		1·4454	0·6916
1·12297		1·4481	0·6890
		1·4501	0·6888
	1·000000645	1·5226	0·65673

TABLE 3.

Data for the Discharge Coefficient of a H.T.P. and the ratio of the Coefficients H.T.P. to Convergent Nozzle.

	1	2	3	4	5	6	7	
h_1 (from Table 2.)	$\frac{--}{Kc}$ at $\frac{p_2}{p_1}2$	$\frac{H}{Kc}$ at $\frac{p_2}{p_1}1$	$\frac{H}{Kc}$ at $\frac{p_2}{p_1}1$ from Fig. 4.	c_2 at $\frac{p_2}{p_1}2$ / c_1 at $\frac{p_2}{p_1}1$ from Table 2.	$\frac{--}{Kc}$ at $\frac{p_2}{p_1}2$ col. 4 × col. 3.	$\frac{H}{Kc}$ at $\frac{p_2}{p_1}2$ from Fig. 4.	$\frac{c\ --}{c\ H}$ at $\frac{p_2}{p_1}2$ col. 5 ÷ col. 6.	mean
7	0·4832	0·8980	1·00101 1·00051 1·00021	0·8826 0·8673 0·8599	0·88351 0·86774 0·86019	1·06525 1·04925 1·03965	0·8294 0·8270 0·8273	0·8279
6	0·5334	0·9024	1·00050 1·00028 1·0	0·8512 0·8392 0·8328	0·85175 0·83945 0·83281	1·05154 1·03844 1·03054	0·8100 0·8084 0·8081	0·8088
5	0·5878	0·9096	1·00015 0·99985 0·99975	0·8196 0·8104 0·8049	0·81972 0·81030 0·80470	1·04000 1·02923 1·02273	0·7882 0·7873 0·7868	0·7874
4	0·6491	0·9193	0·99935 ,, ,,	0·7882 0·7813 0·7772	0·78777 0·78078 0·77665	1·02943 1·02083 1·01630	0·7653 0·7648 0·7644	0·7648
3	0·7180	0·9320	0·99841 0·99868 0·99892	0·7562 0·7515 0·7482	0·75501 0·75050 0·74740	1·01964 1·01342 1·01002	0·7406 0·7405 0·7401	0·7405
2	0·7980	0·9488	0·99702 0·99772 0·99822	0·7240 0·7211 0·7190	0·72184 0·71945 0·71774	1·01041 1·00601 1·00461	0·7144 0·7151 0·7144	0·7146
1	0·8904	0·9708	0·99503 0·99613 0·99703	0·6916 0·6890 0·6888	0·68755 0·68647 0·68684	1·00170 1·00100 1·00050	0·6863 0·6856 0·6864	0·6861
	0·95	0·9863	0·992914 0·994597 0·993232	0·6723 0·6715 0·6710	0·667530 0·667847 0·668204	0·997077 0·997452 0·998022	0·6695 0·6695 0·6695	0·6695
	0·995	0·9986	0·989771 0·991771 0·993221	0·658101 0·658018 0·657961	0·651367 0·652593 0·653496	0·991311 0·99330 0·99485	0·6570 0·6570 0·6570	0·6570
	0·9995	0·99986	0·987298 0·989298 0·990748	0·656861 0·656854 0·656851	0·648556 0·649846 0·650817	0·988657 0·990751 0·992379	0·6560 0·6559 0·6558	0·6559
	0·99995				0·649635 0·648225 0·649196	0·986184 0·988278 0·989906		0·6556 +
0				0·65673				0·6556

NOTE.—The limit in column 4 is not the same as the limit in column 7. In the former $\frac{p_2}{p_1}2 > \frac{p_2}{p_1}1$, consequently the limit would be higher.

TABLE 4.

Values of Kc for $\gamma = 1{\cdot}401812$ (or practically $1{\cdot}402$).

$\frac{p_2}{p_1}$	Conoidal Convergent Nozzle	Hole-in-a-thin-plate $\frac{d}{t} = 48$
0·43	1·045	
0·45	1·0462	0·889
0·47	1·0464	
0·5	1·0448	0·8597
0·52795	1·0409	0·8433
0·55	1·0367	0·8315
0·6	1·0284	0·805
0·65	1·02155	0·7807
0·70	1·0158	0·7587
0·75	1·0109	0·7381
0·8	1·0071	0·7188
0·85	1·00255	0·701
0·90	1·00046	0·684
0·92	0·99927	0·6778
0·93	0·99869	0·6745
0·94	0·99809	0·6710
0·95	0·99744	0·6678
0·96	0·99675	0·66455
0·97	0·99596	0·66128
0·98	0·99511	0·65796
0·99	0·99396	0·65445
0·995	0·99310	0·65238
0·9995	0·99053	0·64973
0·99995	0·98806	0·64811
0·n nines 5	0·988064 $-0{\cdot}0024724n$	0·648113 $-0{\cdot}0016209n$

Communications.

Mr. John L. Hodgson, B.Sc. (Lond.), wrote that the method of determining the discharge coefficients of nozzles and orifices by testing them in series with a standard nozzle or orifice, advocated by the Author, was one which the writer had employed for the past twelve years in the production of air-, gas-, and steam-meters actuated by the difference of pressure produced by the insertion of a nozzle, orifice, etc., in the main to be metered.

The writer had developed the "series" method in several directions to a greater extent than the Author foreshadowed. He had, for instance, found it possible to calibrate nozzles or orifices, which were to be used for measuring air, gas or steam, with water against standard nozzles or orifices. When developing the method, very careful tests were taken with water, air, gas and steam flows through the same nozzles and orifices in order to check out the "laws of comparison" on which the method was based. Tests were also frequently taken by purchasers of the meters who had the necessary facilities. All these tests went to show that even this wide application of the "series" method was satisfactory.

A recent condenser test by Messrs. W. H. Allen, Son and Co., of Bedford, showed that a steam-meter supplied to them was well within 1 per cent of accuracy; while a weighing test on a chlorine-meter supplied to Messrs. Paterson, of London, showed similar high accuracy. Venturi air-meters, supplied by the Author's firm (Messrs. Geo. Kent, London) to the Victoria Falls and Transvaal Power Co., also proved to be equally accurate when tested on a very costly and accurate calibration plant in South Africa. Yet the coefficients of discharge of all these meters were determined or confirmed by water-tests.

The "laws of comparison" on which the method was based were two in number;—

Law 1 :—

The coefficient of discharge (c) for different *elastic* fluids passing through the same nozzle was the same for any given value of the ratio $\frac{\rho_2}{\rho_1}$

$\left(\text{that is, } \frac{\text{density of the fluid at the downstream pressure hole}}{\text{density at the upstream pressure hole}}\right)$.

Law 2 :—

The coefficient of discharge for different *viscous* fluids passing through the same nozzle was the same for any given value of the ratio $\frac{v_1 d_2 \rho_1}{\mu}$ where

v_1 is the velocity of the fluid at the upstream pressure hole.

ρ_1 is the density of the fluid at the upstream pressure hole.

d_2 is the diameter of parallel part of the nozzle or orifice.

μ is the coefficient of viscosity of the fluid.

The coefficient of discharge (c) was defined as the ratio of the actual observed discharge to the theoretical discharge calculated by equating the gain of Kinetic to the loss of Potential Energy of each pound of fluid passing through the nozzle or orifice, without taking into account "stream line" or viscosity effects or the effect of heat received or lost by the fluid during its passage.

Law 1 was, of course, only strictly true when the fluids to be measured obeyed similar laws of expansion, i.e., the $\frac{\rho_2}{\rho_1}$ basis of comparison would not be true for two fluids, one of which expanded according to the adiabatic law and the other according to some widely differing law. Although the writer, in common with the Author and others, has published results plotted on a $\frac{p_2}{p_1}$ basis, he would point out that the proper basis for such plotting is the $\frac{\rho_2}{\rho_1}$ basis ; that is, for gases expanding adiabatically, the $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ basis.*

* Since $\frac{\rho_2}{\rho_1} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ for gases expanding adiabatically.

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The "lazy-tongs" method of correlating results advocated by the Author did not contract the ordinates and abscissæ in the right proportion at all values, and was, in the writer's opinion, not sufficiently accurate. One of the writer's assistants, Mr. ffolliott Gray, was the first to show that comparative results should be plotted on a $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ basis. An interesting example of the method was that, when the coefficients of discharge for a "hole-in-a-thin-plate" of Rateau (who experimented with steam), and Hirn (who experimented with air), which were referred to by the Author, were plotted on this basis, they agreed almost exactly.

The values given in Table 5 had been compiled from Plates III and IV of Rateau's book, "Flow of Steam Through Nozzles," and gave for various values of $\frac{p_2}{p_1}$ the values of the coefficient of discharge (c) for thin plate orifices passing steam and air respectively, as determined by Rateau and Hirn.

TABLE 5.

$\frac{p_2}{p_1}$	c for thin plate orifice.	
	Steam (Rateau).	Air (Hirn).
0·96	0·620	0·616
0·95	0·621	0·621
0·90	0·650	0·640
0·80	0·685	0·680
0·70	0·722	0·695
0·60	0·772	0·738
0·50	0·815	0·785
0·45	0·829	0·800
0·40	0·831	0·811

If these values of c were plotted against $\frac{p_2}{p_1}$, it would be seen

that they lay on two distinct curves. If, however, the corresponding values of $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ were worked out as in Table 6, it would be found, on plotting the values, that they all lay very closely on the same curve.

TABLE 6.

Steam (Rateau). $\gamma = 1{\cdot}135$.		Air (Hirn). $\gamma = 1{\cdot}408$.	
$\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$	c	$\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$	c
0·964	0·620	0·971	0·616
0·956	0·621	0·964	0·621
0·911	0·650	0·928	0·640
0·821	0·685	0·853	0·680
0·731	0·722	0·776	0·695
0·636	0·772	0·694	0·738
0·543	0·815	0·611	0·785
0·495	0·829	0·567	0·800
0·446	0·831	0·522	0·811

The writer's experimental determination of the coefficient of discharge of square-edged orifices, for which the ratio "length of parallel part to diameter of orifice" was $\frac{1}{30}$th, are given in Table 7 (page 1022).

The values given in this Table (which includes lower values of $\frac{p_2}{p_1}$ than any previous Table) were believed to be accurate to within $\pm$ 1 per cent. They were taken by the "reservoir" method with air which had been compressed *isothermally* in a Taylor hydraulic compressor and then slightly warmed in its passage through the main to the test-house. It was, therefore, entirely free from suspended moisture and was also absolutely free from pulsations.

TABLE 7.

$\left(\frac{p_2}{p_1}\right)$	$\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$	c
1·00	1·000	0·608
0·96	0·971	0·612
0·95	0·964	0·615
0·90	0·928	0·625
0·80	0·853	0·655
0·70	0·776	0·685
0·60	0·694	0·720
0·50	0·611	0·756
0·45	0·567	0·780
0·40	0·522	0·800
0·30	0·425	0·835
0·20	0·319	0·860
0·15	0·260	0·872

The values tabulated were the average of tests taken on three square-edged orifices of diameters 0·670 inch, 1·001 inches, and 1·568 inches respectively. The diameter of the main (which was bored) on the upstream and downstream sides of the orifices was 5·995 inches. The pressure-holes were in the plane of the orifice, and the length of the parallel part of the orifices was $\frac{1}{50}$th of their diameter.

The conditions under which the tests were taken made it impossible to work out the results for several months and when the apparatus was no longer available. Each reading was taken with the utmost care, but no points had been, or could be, rechecked, with the exception of the limiting value $c = 0{\cdot}608$, which was the average of many tests.

The values of c for any given value of $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ were slightly lower than the corresponding Rateau and Hirn values. This was probably because the writer:—

(1) arranged the pressure-holes in the plane of the orifice,
(2) used an orifice with a square edge and with only a short length of parallel part,
(3) had the same diameter of pipe on both the upstream and downstream sides of the orifice.

None of these conditions were fulfilled by Rateau or Hirn.* The laws of comparison given did not, of course, enable the coefficients of discharge of nozzles, etc., at values of $\frac{p_2}{p_1}$, which differed appreciably from unity to be determined from the water tests, as it was not feasible with water to work at values which deviated appreciably from unity. The water test, however, gave the limiting value of c when $\frac{p_2}{p_1}$ = unity, which was sufficient to determine within the limits of commercial accuracy the values of c for most designs of nozzle or orifice for values of $\frac{p_2}{p_1}$ between say, 0·98 and unity.

In this connexion, the Author stated, on page 1002, that "as . . . at very small heads the coefficient is in a state of very rapid flux, this figure" (the coefficient of discharge in the limit when $\frac{p_2}{p_1}$ = unity) "is almost meaningless." In the writer's opinion, however, *the coefficient of discharge in the limit when* $\frac{p_2}{p_1}$ = *unity was the most important and useful of all the values to determine.*

[This traversed part of the Author's "conclusions" (2) and (3) page 1010.]

The limiting value could easily be found with accuracy if suitable instruments were used and suitable mathematical methods of evaluating the discharge formula were devised. Such methods were given in equations 14, 15, 16, 17, and in curves 23 and 24 of the writer's Paper on Metering.†

To those who had done much experimental work involving the

* Proc., Inst. C.E., vol. cciv, Part II, pages 150, 152, 153.
† Comples Rendus, 1886.

(Mr. John L. Hodgson.)

accurate measurement of small differential pressures, it was hardly necessary to point out the inadequacy of the apparatus recommended and used by the Author.

The writer had found it impossible, owing to surface tension effects, to obtain accurate, or even consistent readings at low heads with liquids such as mercury and water, neither of which truly "wet" the surface of the tube. No test readings were taken by the writer at less than 3 inches of mercury or 1 inch of water, and this was with gauge-tubes $\frac{1}{2}$ inch external diameter. Yet the Author recommended the use of gauge-tubes less than $\frac{1}{4}$ inch in external diameter.

Readings that were both accurate and consistent to less than $\frac{1}{1000}$ inch could be obtained if oil were used in a $\frac{1}{2}$-inch external diameter (about 0·3-inch internal diameter) gauge-tube. For reading of such high accuracy it was necessary to illuminate the meniscus always in the same direction relative to the line of sight, as otherwise a different shadow or reflection might be read to. A "precision" (microscope) manometer, and a "single tube" manometer, designed and used by the writer, would be found described and illustrated (Figs 15 and 16) in the Paper to the Inst. of C.E. above referred to. The writer had also for some time in use a "curved tube" manometer* having an equally spaced flow scale which at the lowest heads would show accurately without the use of any microscope, a variation of head of $\frac{1}{1000}$ inch of oil.

The writer sympathized with the Author's condemnation of dial pressure-gauges. In his opinion however, they were, when carefully made and when checked against a "dead weight" tester before and after each day's experiments, equally as satisfactory and much more convenient to use than the mercury gauge advocated by the Author. One inherent defect in the dial-gauges—the "lag" between the up and down readings after tapping—could be overcome very largely by using a battery of tempered steel diaphragms such as were used on the steam meters designed by the writer.†

* Proc. Aë Soc., vol. xviii, No. 71, pages 264–5.

† *The Engineer*, 13th June 1919.

The writer considered that the arrangement of the Author's apparatus shown in Fig. 2 (page 983) was open to several criticisms.

In the first place, nozzle 2 was not being tested under the same conditions as nozzle 1, in that nozzle 2 discharged into free air. The pipe should be continued some 10 or 20 diameters beyond nozzle 2.

In the second place, no special care had been taken with regard to the position of the pressure-holes. The Author very rightly called attention to the importance of the orifices tested being geometrically similar, if comparative results of any value were to be obtained—a point to which the writer had also previously drawn attention.* But this geometrical similarity must also extend to the position of the pressure-holes, as the pressure changed very rapidly in the neighbourhood of the orifice.* It was for this reason that the writer in all his plate orifices used pressure-holes which were in the plane of the orifice, this being the simplest way of securing geometrical similarity under commercial conditions.

The type of orifice which the writer preferred to use as a standard was a *square-edged* orifice, the length of the parallel part being $\frac{1}{20}$th the diameter of the orifice. The thickness of the plate in which the orifice was cut should not exceed $\frac{1}{10}$th the diameter of the orifice, and, if it were between $\frac{1}{10}$th and $\frac{1}{20}$th, the orifice should be bevelled off on the downstream side at an angle of 45° so as to leave the correct length of parallel portion. The pressure-holes should be "in the plane of the orifice" as shown at IV, Fig. 17, of the Paper to the Inst. C.E.

The diameter of the pipe upstream and downstream of the orifice should be the same, and should preferably be at least 3 times and, in any case, not less than $1\frac{1}{3}$ times that of the orifice. If it were less than 3 times the diameter of the orifice, special care should be taken to secure good upstream and downstream conditions both for the standard orifice and the orifice to be tested, and to take into account the "velocity of approach" when calculating the discharge coefficient.

* Proc., Inst. C.E., vol. cciv, Part II, Fig. 18, page 132.

(Mr. John L. Hodgson.)

Simplified methods of allowing for the ratio of the area of the pipe to the area of the orifice (that is, of allowing for the "velocity of approach") were given in Appendix II of the Paper to the I.C.E.

Standard orifices should preferably be made of some hard material, such as monel metal, gun-metal, or hardened steel, and ground to ensure that the edge is truly square (without burrs). When the fluid itself was not erosive or corrosive (such as air containing dust or highly superheated steam), square-edged orifices maintained their accuracy for long periods. Such square-edged orifices had the following advantages over any form of shaped nozzle:—

(1) They could be reproduced with ease and accuracy, which a shaped nozzle could not be.

(2) The discharge coefficient, especially in the smaller sizes where the viscosity was of importance (see the second law of comparison), was much more sensitive to variations in the roughness of the surface in the case of a nozzle than in the case of a square-edged orifice. For instance, the viscosity effect would be quite marked at low heads in the small nozzles used by the Author.

The writer had obtained the same coefficient of discharge for orifices of all diameters between $\frac{1}{16}$ inch and 9 inches,* whereas with carefully made small nozzles the coefficient of discharge varied with both the size of the nozzle and the flow. Hence, although the discharge coefficient for a square-edged orifice varied more with $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$† than did the discharge coefficient for a nozzle (which might only vary between 0·95 and unity), its variation depended less upon the finish and workmanship, and the squared-edged orifice for this reason formed the more satisfactory standard.

(3) Finally, the square-edged orifice was cheaper to make than any form of shaped nozzle.

Dr. T. B. Morley wrote that Mr. Jude's method of experimenting and of reducing the results was novel and ingenious.

* Proc., Inst. C.E., vol. cciv, Part II, pages 156–7.

† *See* Tables 6 and 7 (pages 1021–2).

It was to be noted, however, that in the first four experiments recorded in Table 1 (page 1012), the pressure-ratio $\left(\frac{p_2}{p_1}\right)$ was sub-critical. No account of this had been taken in the calculations, and even if the actual critical ratio differed from the theoretical, there was no valid evidence that it differed sufficiently to include within the supercritical range all the experiments referred to. The argument on page 993 that the maximum discharge point was at a lower value than that generally accepted, could not be admitted in this connexion, as the curves on which the argument was based themselves depended on the assumption of the point in question.

If the pressure-ratio were sub-critical, the pressure at the measured cross-section of the nozzle would *not* be equal to the pressure in the space into which the nozzle discharged, and the real pressure-ratio for the inlet and outlet areas would *not* follow the changes of the lower pressure p_2. It was most important that, in calculations of this kind, care should be taken to see that pressures, volumes, etc., appearing in a formula as applying to, say, the outlet of a nozzle, were really those at the section considered. The Author had overlooked this in some of his criticisms of the writer's experiments. For example, he contested the writer's conclusion that for the conditions of his experiments, namely, sub-critical pressure-ratios, thedis charge coefficient for a particular nozzle was constant.

The actual ratio of the "throat" pressure to initial pressure, however, in those circumstances was substantially constant, and the measured nozzle area was that at the "throat." Therefore, on his own assumption that the coefficient was a function of the pressure-ratio, the Author should not expect it to vary in the writer's experiments. His "intuitive" argument at the lower half of page 995 had no force at all, nor on the question of fact did he bring any valid experimental evidence against the writer's curves of $\log p$ and time, the straightness of which he questioned. Many experiments besides those published* confirmed the straightness of these curves, and Mr. Jude's suggestion that

* Proc., I.Mech.E., 1916, "Flow of Air," Fig. 4, page 57.

(Dr. T. B. Morley.)

further research would disturb the writer's coefficients by "at least some three or four digits in the second place of decimals" was quite unacceptable.

As regards accuracy of the coefficients, the Author had misquoted the writer who claimed that the error in his discharge coefficients probably did *not* exceed 1 per cent, for the reasons stated in his Paper.

The different coefficients found by the writer in the case of the orifice were due to the very small (immeasurable) curvature of the edge at the flat side and the corresponding extreme shortness of the inlet, so that it was not reasonable to expect the pressure in the plane of the orifice (that is, where the area was measured) to be either the critical or the final pressure.

With regard to the references in general to the writer's experiments, it must be remembered that the objects were different and that the essentials in the Author's case were secondary in the writer's, whose "orifice" tests, for example, were carried out simply in order to compare with the nozzles an orifice similar to one known to have been used by a consultant in commercial work.

The writer agreed with the Author in his general criticisms of "orifices-in-thin-plates," and, on account of the difficulty of specifying and measuring the form of the edge, recommended the adoption of nozzles instead.

The writer's principal object in his tests was to *compare* nozzles as regards velocity efficiency, and in order to carry out the "reaction" tests for velocity it was necessary to adopt a comparatively small chamber at the nozzle. This was the reason for the pipe-connexion characterized as "extremely bad" by the Author. Experiments with different approaches to the nozzle showed that its adoption was justified. The writer agreed, however, that, for the determination of coefficients intended to be as nearly as possible absolute standards, a large full-way connexion at the nozzle, as proposed by the Author, was preferable.

The Author wrote that he hardly knew how to take the small response to the invitation for discussion, but would not be tempted

to assume that he had cleared the particular ground he had laid out so that few thorns were left. Admittedly his Paper was rather involved and difficult to follow, just as similar papers were difficult because busy readers had not the time to place themselves in the position of the mathematical student, who could only acquire his subject by plodding through it letter by letter, and because the exigencies of space demanded considerable and dangerous abridgment. He therefore all the more appreciated the contributions of the two members who had replied, although he felt obliged to break a friendly lance with them.

The Density Basis.—The Author was glad to have Mr. Hodgson's suggestion of a rational definition of the "lazy tongs" basis of comparison for different gases. They amounted to much the same thing above the critical ratio at any rate, since the curve of $\frac{p_2}{p_1}$ and $\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}$ was sensibly straight. Below that ratio the density method did depart more appreciably from the lazy tongs. In any case the density method was the more easily applied. Mr. Hodgson's examples, however, suffered from a little misfortune. He expressed satisfaction at the close agreement of the Rateau and Hirn H.T.P. results. He then proceeded to demolish his point by giving another table of his own coefficients, the values of which differed considerably more from both than the former did from one another at their worst. Surely, if the former two made with different gases, nozzles, and apparatus now agreed so closely, Mr. Hodgson's figures should likewise agree? Euclid could not be thrown over altogether. Rescue from demolition really came from the fact that there was still sufficient divergence between the Rateau and Hirn H.T.P. results to admit a third (and *a fortiori*, Fig. 1.) and that the writer's Table 7 (page 1022) apparently did not give the coefficients of discharge at all. But the density method was only an approximate one, because any index γ could only be associated with one critical $\frac{p_2}{p_1}$ by the assumed law of expansion, and the criterion for comparison was that $\left(\frac{p_c}{p_1}1\right)^{\frac{1}{\gamma 1}} = \left(\frac{p_c}{p_1}2\right)^{\frac{1}{\gamma 2}}$. Such an identity was

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impossible. Between steam and air $0\cdot577^{\frac{1}{1\cdot135}}$ should equal $0\cdot528^{\frac{1}{1\cdot402}}$; but it was not so; nor was there any other associated pair of values that would yield either. The method therefore failed to provide a common abscissa for the coefficients with different gases.

Position of Pressure Holes.—Mr. Hodgson did not put into practice his definition of the coefficient of discharge when he insisted on the pressure measurements being at the inlet and outlet planes. In spite of his certain knowledge that all nozzles (round, square, oblong, long, short, leak-holes, football-field gates, etc., etc.) appropriated to themselves an indefinite amount of space both behind and in front, he would take pressures at places where stream-lines were well established, and figure his energy equations solely on those pressures, in defiance of his definition and remarks, the velocities at those places being inaccessible. · Stream-lines, viscosities, friction, etc., were all functions of the coefficient itself, and all went into that common receptacle. The proper place, then, for measurements for the purpose was in the infinite reservoirs behind and in front where the conditions were static. That was one reason why equation (a) had to be arranged to exclude ${}_1r_2$ and ${}_2r_2$.

Referring to the further Fig. 10 in which were plotted the surface and continuation pressures for a serial variation of form of nozzle, the absurdity of plane measurements should be apparent. These particular nozzles represented the "wind-way" of organ-pipes, and one of the things associated with the experiments was to find out how much wind they would let out (*see* inset for first approximation coefficients of discharge) from the quite large reservoir formed by the "boot" or foot of the pipe in which the pressure was p_1. The same thing applied to the H.T.P. or other hole of any shape or section whatever. These curves dealt with a very light pressure and an unfamiliar kind of nozzle, selected for this very reason, and because Mr. Hodgson's Fig. 18 (Proc., I.C.E.) did not bring out the point he wished to make but fell over. His coefficients of Table 7 were therefore not the true coefficients of discharge at all, unless they had been the subject of a calibration not revealed.

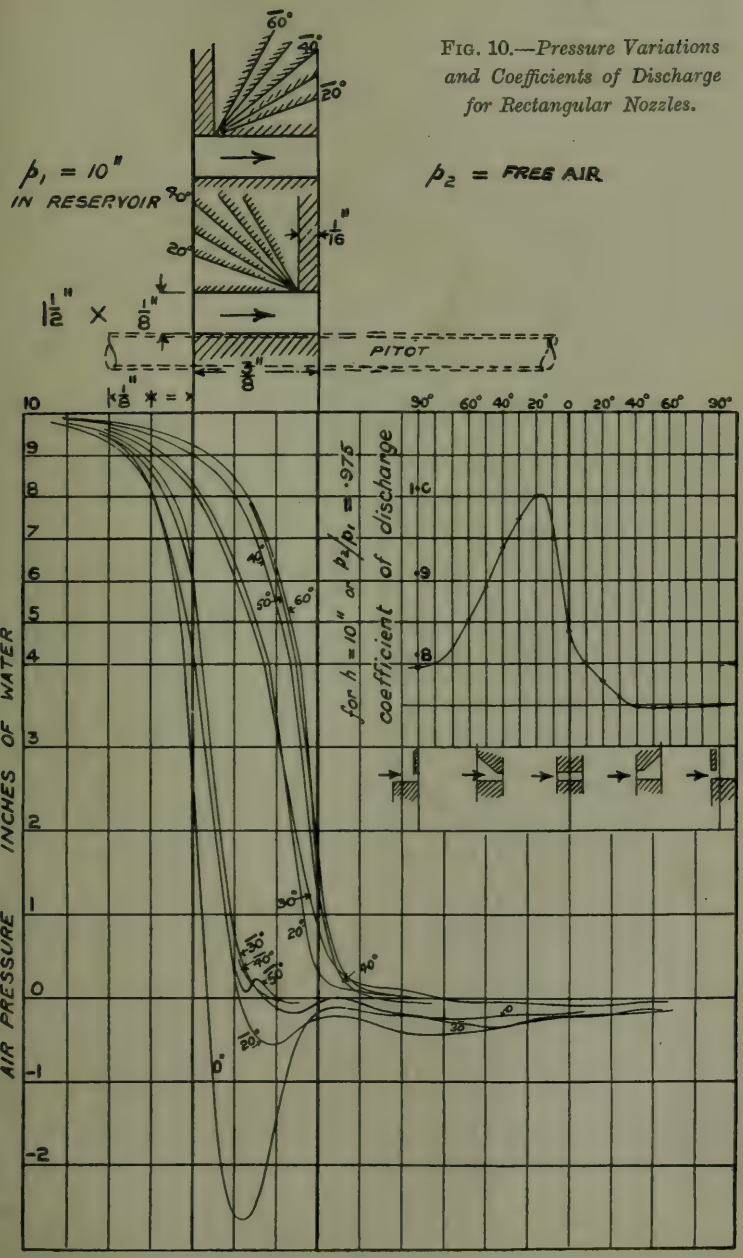

Fig. 10.—*Pressure Variations and Coefficients of Discharge for Rectangular Nozzles.*

(Mr. A. A. Jude.)

The Author readily admitted that an orifice with plane pressure connexions inserted in a pipe was a feasible testing instrument, but being the subject of a calibration curve as described by Mr. Hodgson in his Paper to the Institution of Civil Engineers, and by Mr. Gaskell in another Paper to the same body (vol. cxcvii), could never be trusted *a priori* without being submitted to an actual calibration. In fact, for this reason, the Author found the method rather a nuisance in varied commercial work, the orifice itself requiring more testing than the machine to be tested; but this was not to rule it out for permanently fixed instruments and meters.

Mounting of Nozzle.—Mr. Hodgson's remarks in regard to the relative size of nozzle and pipe appeared to be rather inconsistent. In his Inst. C.E. Paper, he showed that a value of m or n of more than about 10 was not significantly against the pipe being considered as a reservoir; in his present remarks, he, in other words, mentioned 9 as a reasonable limit, whereas, in the Author's apparatus, the value was no less than about 370, corresponding, for example, to a 6-inch hole in a 10-foot wall. His criticism that the outlet nozzle should have had a corresponding pipe extension therefore had no point. In Mr. Hodgson's own showing, the apparatus did provide a substantial equivalent to the infinite reservoir in all three places. So, the criticism that "no particular care had been taken with regard to the position of the pressure holes," fell to the ground.

The best place for a test-nozzle was on a comparatively large reservoir, discharging freely to the air or other large reservoir such as a condenser, and this was the only typical condition the Author included within the scope of his Paper. Obviously, no control-valve must come between the reservoir and nozzle; it must be at the inlet branch. This condition was the proximate one for the nozzles of turbines, the example above, and other generic applications. On his part, the Author considered he was justified in criticising Dr. Morley's apparently very small value of n, and because it was associated with the disturbing elements of a cock and various corners too close to the nozzle to put things sufficiently beyond question. Dr. Morley had since provided the Author with the actual value of n—about 25 to 30. His criticism was therefore

willingly modified, but he still thought it would be better to place a bigger "reservoir" between the cock and nozzle.

The Limit Coefficient when $\frac{p_2}{p_1} = 1$.—Here Mr. Hodgson and the Author disagreed. For the convergent nozzle, Rateau (Fig. 1 here), Mr. Hodgson (Fig. 17, Inst. C.E.) and Author (Fig. 4) all agreed that the characteristic curve swept round tangentially to the axis. But for the H.T.P. the Author was at variance by declaring that its characteristic also swept round, his predecessors concluding that it ran tilt into the axis.

Now there was no obligation to suppose two equal and similar nozzles in series; they might be of equal throat area, but one (1) a good and the other (2) a bad one. In that case it was evident that c_1 was always greater than c_2 (liquid or gas) up to and including the limit. If it were not so, it followed that the h_1, h_2 line, as in Fig. 3 (pages 980–1), must finish at 45°. Now the experimental and geometrical evidence was against this, except conceivably for such infinitesimally small values of h that by the time the inclination of 45° set in, the values of c_1, c_2 had already fallen below the alleged butt-end limit.

Again, it seemed to be missed that if *every* physical factor were included in equations of flow, there would not be such a thing as a coefficient of discharge; it would always be unity, because everything would be accounted for. Consequently, it would be agreed that as the head of pressure diminished, so might the values of the omitted factors become predominant, until there was nothing left but themselves. Therefore, the coefficient must surely be zero at the limit, whether it be when $\frac{p_2}{p_1}$ is unity, or has that slightly less, but not necessarily constant, value, where the unregistered factors stem the flow. Thus, zero is indicated on two lines of argument. If for the H.T.P. c were unity all along the visible line, something might be said against this.

The question of tangential contact was, perhaps, one of degree, for with the H.T.P., the Author himself had shown that it was only just visible on a large scale of ordinates, and therefore was liable to be missed except by the special form of analysis provided

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by the series apparatus. But it was rather straining matters, except as a rough commercial approximation, for Mr. Hodgson to set up as a mathematical truth, a rectilinear equation (page 133, Inst. C.E.) to represent an irregular curve (Table 7), and to establish therefrom a limiting value, quite apart from the question surrounding the figures of that Table. The conspicuity of the bend obviously depended upon the relative effects of the intangibles.

The Author accepted Mr. Hodgson's qualification for *minimum* size provisionally, but was of opinion that the qualification might vanish with workmanship for anything above capillary sizes.

Mr. Hodgson's third paragraph (page 1023) was entirely misconceived. The coefficient referred to was clearly enough Hirn's, and not the writer's parenthesis. Further, the Author has spent so much time and space in discussing the limit, that he could only marvel at the writer's last sentence.

Gauges.—Mr. Hodgson's experience with a water-gauge was evidently unfortunate, and the Author could only suggest that some difference in the method of application and observation accounted for the difference of opinion. Anyway, the Author had no difficulty in obtaining both accurate and consistent readings, as witness, for example, the minute wave forms of Fig. 10, and the unexpurgated spots of Fig. 3. But Mr. Hodgson, in spite of his long use of the series method, seemed to have missed its power of eliminating the possible instrumental errors of which he complained.

He was quite at a loss to understand Dr. Morley's opening criticism. The necessary calculations involving the sub-critical portion of the date *had* been made, and were discussed with reference to curves D. E. H., Fig. 4, etc., and the position of maximum discharge did not depend on an "assumption" of the critical point, since that point arose from the theoretical conception pv^n = constant. But Dr. Morley went farther by assuming that the throat pressure was that given by this conception. In his own experiments he disclaimed any attempt to measure it (page 59, 1916 Proc.), but now he said that the "ratio of throat to initial pressure was substantially constant."

How could he know this? It might be; and it was to be hoped

it were so for the same over-all ratios in any rank. Assuming it were so for any given sub-critical ratio whatever the rank, Dr. Morley's straight lines would be quite correct if his coefficients were referred to the critical ratio for the datum, but—and this appeared to be the crux of the difference of opinion between them—it did not follow that they were straight when the flow was disturbed by a *variable* after-drop, that from critical pressure or its substitute and the "free" reservoir. Now, practice was not concerned with what appeared to be Dr. Morley's aspect, but with the latter condition; and it was just this condition which tended to alter the internal wave forms, and to vary the coefficients a few per cent as submitted by the Author. For supercritical drops, Fig. 10 showed that the writer's implication in Par. 2 (page 1027) that the pressure at the end of a convergent nozzle was necessarily p_2, was not correct. As a further matter of fact, the pressure was not even uniform across any normal plane. The Author, therefore, felt compelled to repeat that, for gases, the pressure along the nozzle might be anything but the "theoretical," and that the discrepancy between the more or less abridged theory and the actual occurrence should be regarded as a function of the coefficient; again, that nozzles were not necessarily of a circular, symmetrical form—might not have even a "throat," for example, a labyrinth, or a definite outlet plane, for example, that sometimes indescribable affair, a turbine nozzle—and that "discharge" was the amount of stuff that got through somehow from one side to the other; how, it did not matter much here.

Referring to Dr. Morley's Fig. 4, it would be seen that the straight lines continued well into the super-critical range (below 28 lb.). If he would integrate his equation, he would find that the time for completely emptying the reservoir from 20 lb., when $c = 1$, was about 3·3 minutes, which value would locate the pseudo-origins. Now it was well known that the coefficient for convergo-divergent nozzles was greater, sometimes much greater, than unity (for example, the Venturi tube; see also Proc. 1913, p. 294) for large values of $\frac{p_2}{p_1}$. So, since the coefficients of some of those nozzles,

(Mr. A. A. Jude.)

while others did not, passed from less than unity, through greater than unity (possibly 1·2 or so) down to zero at the limit, which pronounced and variable characteristics were not indicated either by (Morley) Fig. 4 and Table 2, the Author submitted that there was yet something unexplained in those straight lines, the lower end of them, at any rate. The nature of the difference of opinion, or of statement, in regard to the body of the lines had already been indicated.

The Value of K.—The concluding question now arose, "Had a more definite value of K (and thence of c absolute) for the two elementary types of nozzle been ascertained from this discussion? Reasons had been given why Mr. Hodgson's values, Table 7, could not be accepted. Further, if the derived values of K were set out in a parallel column of Table 4, it would be seen that they varied from 0·88 at the top to 0·938 at the bottom, that is, K was not there a constant. Neither critic had challenged K being a constant; indeed, there seemed nothing against it, because it was simply the factor representing the displacement of the axis of X. Mr. Hodgson's H.T.P. coefficients, therefore, fell again, if the constancy of K, when applied to Table 4, were really a test. Alternatively, the whole of the Author's derivations went over, but the writers had not indicated the flaw. Possibly the writer's coefficient, 0·608, for the H.T.P. $\left(\frac{d}{t} = \text{about } 50\right)$ at the pseudo-limit, was acceptable, for, so far as the Author could read between the lines, this value might not be the subject of the calibration apparently necessary farther along the scale. If so, the value of K now established was 0·938 instead of 0·9551 as deduced from a combination of earlier results (page 1003), and the values of Fig. 9 were about 1·7 per cent too high. But its acceptance meant the rejection of the so-called "excess discharge" of the convergent nozzle, the existence of which was maintained by other writers.

So, beyond this possible admission, the question must regretfully be answered, "It had not," and the Author's concluding point (3) remained. Point (4) required a qualification, owing to the inadvertence of a non-self-checking figure, corrected in the final

proof. Points (1) and (2) must still be left to the verdict of the future. The Author noted with pleasure Mr. Hodgson's long-time use of a series method, although apparently they differed a little in their methods of application. He also expressed to the Council his appreciations for the large amount of space and attention granted to this absorbing subject.

ADDRESS BY THE PRESIDENT,

Captain H. RIALL SANKEY, C.B., C.B.E., R.E., ret.

Although I have already expressed my sincere thanks to the Members for having elected me to the Presidency of an Institution whose importance grows year by year, and whose influence is making itself felt not only throughout Great Britain but also throughout the Empire, I desire to renew my thanks after eight months' experience. It is a very honourable post, full of interest and responsibility, but it could not be successfully filled without the help and cordial support of the Members of the Council and of the Staff, and in this they have never failed me, and I tender to them my sincere thanks.

Due to the enforced holiday of our esteemed late Secretary, Mr. Worthington, I feared that I would have some difficulties, but, owing to the zeal and knowledge of Institution matters shown by Mr. Chapman, these difficulties did not arise, and I desire especially to thank him.

As might be expected, a number of Papers have been read or will be read before this and other Engineering Institutions, dealing with the application of engineering during the Great War. As I was privileged to be officially connected with certain sections of engineering work during the War, I thought that some of the non-confidential information which I thus obtained might form

the subject matter of my Presidential Address, and it might thus be one of the group already referred to.

The catch phrase, so common in the early days of the War—"this is an Engineers' War"—was undoubtedly substantially true, and in a greater measure in this than in past wars. It is generally supposed that there is a clear-cut division between military engineering and civil engineering (in the broad sense of the Charter of the Institution of Civil Engineers), but it is nevertheless impossible to say where, in the Great War, military engineering ended and civil engineering began.

It will be agreed that in the front trenches it was purely military engineering, and that in the back areas it was the application of civil engineering to the purposes of war. The difference between this and its ordinary application lies in the change of the relative importance of economy of construction, the time required for the work, and the reduced factor of safety.

In military operations time is the ruling factor, and economy of construction is subservient. Nevertheless economy in the broad sense was observed, because even exorbitant cost, if it results in the construction of some engineering structure or in the supply of some munition of war by the time required, may greatly affect or even decide the issue of an operation on which the whole successful termination of the War may depend. The above must not be construed as a premium on extravagance, but rather to indicate the nature of the financial decisions that had to be made by those responsible for the conduct of engineering matters during the War.

It will be freely admitted that at no period has the value and importance of engineering to the community been more apparent than during the War. Without it the Army, the Navy, and the Air Force would have been rendered powerless.

Of all the forms of engineering, mechanical engineering had the lion's share, both as regards the volume of work done and expenditure. As a proof of this statement, one need only consider what could have happened if the mechanical engineers had been removed.

As a general statement, it may be said that the essential object

was to throw "stuff" at the enemy, and that "stuff," whether bullets, shells, bombs, poison gas, or flames, was made by mechanical engineers or by machinery supplied by them. The "Apparatus" for throwing the "stuff," whether rifles, guns, projectors, or aeroplanes, was made by mechanical engineers, and, lastly, they were intimately concerned with the means of transporting the "stuff" and the "apparatus" from the workshop to the position where used, whether by means of motors, lorries, railways, or steamships.

Apart from mechanical engineering, mechanical engineers in general, and the Members of this Institution in particular, rendered other services to the country which cannot be exaggerated, and the Roll of Honour which is about to be unveiled, is an eloquent testimony of such services.

As already stated, every branch of engineering contributed to the final and satisfactory issue of the War, but in this Address I propose to limit myself to that portion of mechanical engineering of which I have had personal experience during the War, both in France and at home, supported by information I have been able to obtain.

The work of the mechanical engineers at the Front was carried out principally in connexion with the R.A., the R.E., R.A.S.C., R.A.O.D., the Air Force, the Tank Corps, and the Railways, and in general the machinery requiring repair by each was as follows. The repairs were in some cases not carried out by the Corps itself —for example, gun-tractors were repaired by the R.A.S.C.

TABLE 1.

Machinery subject to Repair, in use by various Corps.

Royal Artillery.

Guns and Gun Carriages, various Mechanical Lifting Appliances, Tractors for Guns of various calibres, Range-Finders.

Royal Engineers.

Steam-Engines (stationary and portable) Oil-Engines, Petrol-Engines, Electric Generators and Motors, Pumps of all kinds, Ventilating Fans,

Mining and Digging Machinery, Hydraulic Pumps and Rams, Printing and Lithographic Machinery, Stone-Crushers, Branch Railway material of all kinds, and Telegraph, Telephone, and Wireless Apparatus.

Royal Army Service Corps.

Horse-drawn Wheeled Vehicles, Mechanical Wheeled Vehicles, Petrol-Engines, Laundry and Bakery Machinery, Stationary Steam- and Oil-Engines, Steam and Petrol Tractors.

Railways.

Locomotives, normal and narrow gauge, Wagons of various types, normal and narrow gauge, Petrol and Petrol-Electric Tractors.

Tank Corps.

Petrol-Engines and Gear.

In the early days of the War, the extent to which mechanical engineering would be employed was not realized, which is evidenced by the fact that repair shops of any magnitude were only started at the beginning of 1917, but then rapidly developed both as to numbers and size into a huge organization. I propose to say a few words about some of these repair shops erected on the French Front, most of which I had an opportunity of inspecting.

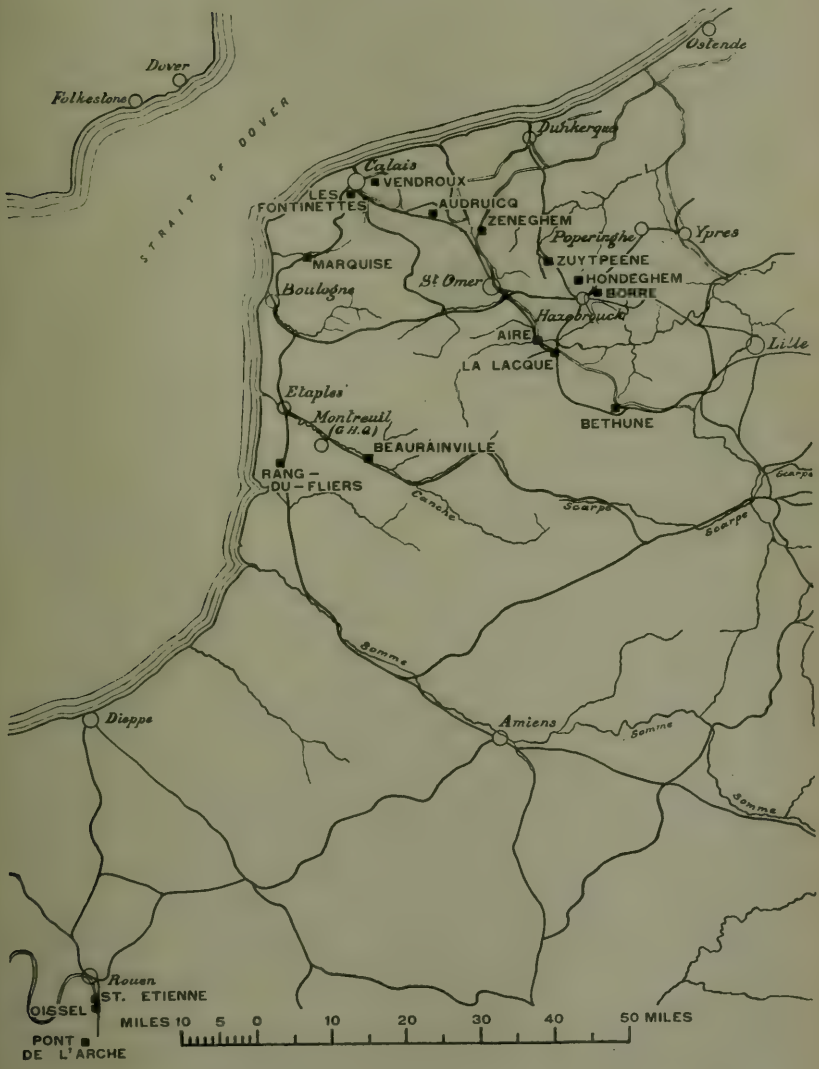
As a rule the buildings were of a temporary nature, but in some cases existing buildings were adapted. The machines and tools were of the best description, and the lay-out and organization were quite on a par with the best Works at home.

Some of the principal Works erected were as follows :—

Locomotive Repair Works.—These were divided into works to deal with the normal gauge stock and with the light railways, principally 60-centimetre gauge.

In the early days of the War the British Headquarters Staff did not anticipate a heavy programme of railway construction, it being expected that this work would be done by French troops, and the intention was for the British troops to assist the Belgians in repairing the lines through Belgium.

Map of Northern France showing positions of the places, etc., mentioned in the text.



Some idea of the ultimate magnitude of the railway operations will be gathered from the following: In an area approximately 10 miles broad by 10 miles long south-west of Ypres there were established 200 railway stations both normal and narrow gauge. The total mileage of normal gauge laid by the British troops during the War on all counts was 2,639 miles, and owing to heavy traffic and enemy action, the repairs of the rolling stock was very great. The amount of this rolling stock in use at various periods is shown in the following Table.*

TABLE 2.

Locomotives and Wagons (Normal Gauge) provided by the British (Totals at the dates given).

——	31/12/16	31/12/17	31/12/18
Locomotives :—			
Imported	62	753	1,205
Hired	198	215	229
Captured	—	—	6
Total . .	260	968	1,430
Wagons :—			
Imported	3,840	34,845	52,597

The first provision for the mechanical engineering in connexion with the Railway Construction Troops was on a very small scale, and consisted of the appointment on the 29th September 1914 of an officer with the rank of captain whose duty it was to cope with the erection, preparation, operation and maintenance of special plant, such as pile-drivers, breakdown cranes (one of 35-ton lifting capacity which was put into commission in April 1915 †), and pumping plant.

* A slide showed the French lines over which British locomotives worked.

† Slides of this crane of the Audruicq Works were shown.

The right-half of a new R.E. Co. No. 118 was detailed for the above duties, but was only brought to full strength in August 1916, two years after the declaration of War. This unit had a small machine foundry, pattern shop and saw mill, and a mobile train repair shop.

It was only in April 1917 that the matter was really taken up seriously, when the Chief Mechanical Engineer's Department was formed, and works were started at Audruicq, and were laid out with the object of repairing some thirty Belgian locomotives, and of erecting 2,500 railway wagons (ultimately increased to 10,000) shipped from Canada. The capacity of these shops was such as to be able to deal with 400 wagons per week. Later these works were extended to deal with the repairs of normal gauge locomotives.

When the German advance of May 1918 occurred, the Audruicq Works were dismantled and the locomotive part was sent to St. Etienne, near Rouen, where repair works had been established. Works near by, at Oissel,* were prepared for wagon repairs, with a capacity of 160 per week, in case Audruicq had to be abandoned. As a matter of fact it was not abandoned, and therefore the Oissel Works never came into operation.

At St. Etienne advantage was taken of the materials already available for the construction of three bays of the railway works extension which had been projected before the War. They consisted of an erecting shop, 830 feet by 81 feet 6 inches, giving accommodation for dealing with forty engines and provided with 40-ton and 20-ton travelling cranes ; a machine shop, 830 feet by 65 feet 7 inches, and a boiler shop, 830 feet by 81 feet 6 inches.

A forge was placed in the boiler shop and a foundry was established close by. Work was begun in February 1917, and the machine-tools were temporarily driven by oil-engines (awaiting the completion of the power station), in order to erect locomotives shipped in parts from the United States of America. After the German advance on Amiens in March 1918 a part of these works† was handed over

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* A slide of these Works was shown.

† Slides of these Works were shown.

to the Nord Railway of France. Some of the principal work done at these shops was the erection of British locomotives, repairs of the Belgian locomotives parked at Oissel, the maintenance of R.O.D. locomotives (forty per month), and the manufacture of spares. Amongst the personnel for these shops were two Prisoner of War Companies of selected tradesmen.

The erection of locomotive shops had also been started in November 1916 at Borre,* on the Hazebrouck–Poperinghe line, for the repair of locomotives working into Belgium. These works occupied seven acres and were capable of dealing with twenty heavy repairs per month, and also manufacturing locomotive spare parts. The buildings were of corrugated iron, 140 feet by 41 feet 9 inches for the works, and 70 feet by 414 feet 9 inches for stores. The works contained a full complement of tools, including two wheel lathes, one supplied by the G.N. Railway and one by the Midland Railway.

These works became untenable owing to the German advance of March 1918. The shops were stripped and the plant removed under shell fire in four days and sent to Audruicq on the way to Rang-du-Fliers, which was laid out to repair twenty locomotives per month, but was completed too late to be of any real service.

Light Railways.—It was only in the late summer of 1916 that a comprehensive system of light railways, principally 60-centimetre gauge was considered, and an estimate based on 1,000 miles of track was prepared. According to the position of the track 9 lb., 16 lb., and 20 lb. rails were to be used, and the original weight of the locomotive was limited to 7 tons for the 9 lb. rails, and for working on the heavier rails 14 ton Hunslet, 14·5 ton Baldwin, and 17·2 ton American Locomotive Company locomotives were ordered. Electric traction was considered, but was abandoned in favour of steam. Subsequently petrol tractors and petrol electric tractors were obtained. Of the former the 10 h.p. were suitable for forward tramways, and the 20 h.p. and 40 h.p. for the 16 lb. and 20 lb. rails for use some way behind the immediate front.

* A slide of these Works was shown.

The following Table shows the original estimate and subsequent provision actually made :—

TABLE 3.

Light Railways (*Principally* 60-*cm. gauge*).
Length of Track and Rolling Stock.

——	Original Estimate 1916.	Actual Provision.
Track . . . Miles	1,000	3,470
Locomotive (Steam) . . .	800	835
Petrol Tractors . . .	100	1,030
Petrol-Electric Tractors . .	200	200
Double Bogie Trucks . .	2,000	3,940
Steel Well Trucks . . .	800	2,310
Four-wheel Box Wagons . .	—	2,350
Tip Wagons	750	7,665
Hand Trolleys	—	1,100
Gun Carriers	—	224

The American locomotives required considerable overhauling and were too stiff at first, causing derailment, but they rapidly worked loose and, in fact, became too loose. In the Hunslet locomotives better attention had been paid to the clearances. They ran freer at first, and did not get slack so soon as the American locomotives. The petrol tractors were found preferable in the forward areas, owing to less visibility than the steam locomotives. They were provided with shields and were called " protected " and " armoured " according to the amount and the thickness of the steel protecting plates.

The wagons were principally of the double-bogie type, and there were also four-wheeled box wagons. Certain wagons were

arranged so that gun-carriage frames for 6-inch howitzers could be attached. The operation of attaching or detaching took five minutes. Some of these frames were specially strengthened to deal with 8-inch howitzers and 60 pounders.

Prior to the autumn of 1917, Decauville locomotives, etc., were repaired in a corner of the Audruicq yard. In November 1916 a scheme was prepared to build a central shop near Bethune, but it was considered to be too near the enemy lines and finally a site at La Lacque, near the Berguette Station and close to the Aire Canal, was chosen. The approval was given on the 31st December 1916. Many difficulties were encountered with regard to the site, and the erection was much delayed by frost and wind. The smith's shop was at work 177 days after approval. The first machine-tool was turned round in 184 days, and the work started normally in 209 days. These works were exposed to hostile airmen and long-range shell fire and received two direct hits. The main block was 400 feet long by 200 feet wide.

On the occurrence of the German advance in May 1918, the locomotives were sent to England for repair, and the machinery was sent to Zeneghem for storage until the new light railway repair shops (started in May 1918), at Beaurainville, were ready for their reception. These shops were of considerable extent, and the first machine started running on the 21st July 1918.

The final provisions for repairs of light railway rolling stock were as follows :—

1. A central workshop (originally sited at Aire).
2. Six army repair shops.
3. Six 60-cm. gauge mobile repair shops, consisting of machine power and air-compressor van, fitting shop, stores and an office van.
4. Repair shop at Richborough (towards the end of the War).
5. Two normal-gauge mobile repair shops.

The following Table shows the output of the various railway repair shops in France :—

TABLE 4.

Output of the various Railway Repair Shops in France, both Normal and Narrow Gauge, during 1918.

Locomotives :—	
Erected	246
Repairs in Shops, heavy and light	809
Repair in Running Shed	5,487
Washing out	25,813
Wagons :—	
Erected	3,434
Repairs, heavy and light	22,639
Ambulance Trains :—	
Repairs	104

(There were 41 Ambulance Trains).

Important mechanical engineering work was done at various docks, such as those of Dunkerque, Calais, Boulogne, Dieppe, and Le Havre. At Dunkerque, for instance, forty electric cranes and fifty steam-cranes were erected, as well as four transporters for discharging coal.

As regards the latter, post-war traffic of ore from Lorraine and of coal from this country was not lost sight of, and consequently provision was made for placing in position and unloading a 1,000-ton ore-train into a ship, charging it with 1,000 tons of coal and dispatching it, the whole operation to take three hours. For this purpose a grid-iron was laid and travelling transporter-cranes and transporter-belts were provided, together with silos for the storage of coal and of ore to meet the case of a ship not being in dock with coal or of the non-arrival of a train with ore.*

The volume of traffic and its rapid increase will be realized by the statement that at the 31st December 1916, 126 cranes were at work for the British at various ports. At the 31st December 1917 this number had risen to 290, and at the 31st December 1919 to 369.

* A slide showed an outline of the design for the above.

Aeroplane shops were erected at Pont de l'Arche, near Rouen. These shops were quite extensive and were laid out on up-to-date modern lines. The machine shop had a perfect and complete outfit of modern tools of all descriptions of the kind required for small accurate work. The power station consisted of oil-engines aggregating 400 h.p. The buildings were of a temporary nature.

Extensive repair shops for motor-lorries were established at various places; they were known as the Heavy M.T. Repair Shops.

Some particulars of these shops are given in Tables 5 and 6 (pages 1052–1054) :—

The 4th M.T. Shop (Rouen) had a fine machine shop and fitting shop, and a very large shop for the repair of magnetos, sparking plugs, etc., extensive enough to accommodate 1,000 men, who were German prisoners.

The magnitude of the various repair shops I have referred to, gives some idea of the amount of machinery at the Front requiring repair, but it must be remembered that this machinery was exposed to great risks and suffered injury from enemy fire, and was running under much more onerous conditions than in peace time, as, for example, the effect of the state of the roads on motor-vehicles.

The following are a few examples of the use of machinery which I had the opportunity of inspecting.

In connexion with the petrol depot at Les Fontinettes, near Calais, capable of dealing with the dispatch of 200,000 gallons per day, a factory was erected for making petrol-cans, starting with tin sheet. The sides and ends were pressed by means of Bliss machines, assembled together, beaded over and then soldered. The cans were tested by air pressure, then dipped into paint and stacked. The capacity of the plant was 7,000 tins a day.

Machinery was used at the quarries for driving the air-compressing plant for rock drills and the stone-crushing machinery. The power required at the Marquise Quarries, for instance, was 2,000 b.h.p., and consisted of oil-engines, suction-gas engines, and portable steam-engines, also electric power obtained from the existing power-station. The output of this quarry was 6,000 tons of road metalling per day.

A large bakery was established at Calais, capable of dealing with 500,000 loaves per day, fitted out with the latest machinery. There were fourteen stores, each holding 50,000 loaves, and on one occasion a bomb fell in one of the stores, and the loaves prevented any casualties.

An extensive printing works was established at Calais, consisting of Linotype machines, ordinary printing press, stereo outfit, and the usual accessories.

A great variety of types of machinery was used, such as roadscrapers, conveyors, pneumatic oat-dischargers, steam-navvies, and pile drivers.*

Some of the military workshops in France undertook manufacture, and the following are a few examples :—

At Hazebrouck an existing workshop was taken over and several patterns of hand grenades were made there. This work continued until driven out by shell fire.

The erection of an electrolytic plant was started towards the end of the War near Rouen to produce hydrogen and oxygen, but at the time of my visit in February 1919 it was still unfinished and was being completed for sale to a French firm. The system adopted was the Electroliseur Geeraerd. There are 200 cells, requiring 2·2 volts each. By means of glass louvres the electrolyzed oxygen and hydrogen are kept separate and conducted to different pipes and gas-holders. The oxygen is passed through incandescent platinum in order to burn out the impurities and any remaining hydrogen. The power is obtained from two 340-kw. Crompton machines, driven by Mirrlees-Bickerton Diesel engines. The capacity of the plant is 50,000 cubic feet of oxygen and 100,000 cubic feet of hydrogen per day. By means of a four-stage Brotherhood compressor, the gases are compressed at 2,000 lb. per square inch into the usual cylinders.

Water Supply.—The water supply to the Army was one of the most essential and important operations, and the mechanical engineer had his fair share of the work. As this subject will be dealt with at

* Slides of these types of machinery were shown.

TABLE 5 (*continued on next page*).

Heavy Repair Shops. Mechanical Transport.

Name of Works.	1st.	2nd.	3rd. A.
Purpose . . . Repair of	Lorries.	Lorries and Motor Cycles.	Motor vehicles, all classes.
Locality	Plaine St. Denis.	Rouen.	St. Omer.
Whether under fire . . .	Yes. "Big Bertha."	No.	Bombed intensively.
When started	Sept. 1914.	Feb. 1915.	May 1915.
When got to work . . .	At once.	At once.	At once.
Period in use . . Years	$4\frac{1}{2}$.	$4\frac{1}{4}$.	3.
Type of Building (whether permanent or temporary) . .	Permanent.	Mainly permanent.	Permanent.
Floor space . . Sq. ft.	100,000.	85,000.	94,000.
Value of Machines installed .	£5,000.	£7,000.	£4,000.
Lifting Tackle	Light.	Shipyard travelling crane (heavy).	Light.
Men employed: Military . .	800.	800.	800.
Prisoners of War . . .	—	500.	—
Quantity of Work executed during the period.	4,800 vehicles overhauled.	3,920 lorries, cars and motor cycles.	5,650.

TABLE 5.

Heavy Repair Shops. Mechanical Transport.

3rd. B.	4th.	5th. A.	5th. B.
Motor-cars and motor - ambulances.	Repairs to Accessories and parts.	Repairs to Lorries.	Repairs to Lorries.
Honfleur.	Rouen.	Bergnes, near Dunkerque.	Rouen.
No.	No.	Yes.	No.
May 1918.	Jan. 1917.	Nov. 1917.	April 1918.
Aug. 1918.	May 1917.	Not used.	Aug. 1918.
1—till May 1919.	2½—till Sept. 1919.	—	—
Converted timber store—Galvanized steel additions.	Steel frame—Galvanized sheet, walls and roof.	Steel frame—Galvanized sheet walls and roof.	Steel frame—Galvanized sheet walls and roof.
108,000.	234,300.	120,000.	140,000.
£4,000.	£30,000.	£14,000.	
Light.	Light.	Light.	Light.
500.	250.	—	570.
500.	3,500.	—	450.
—	Vehicles repaired, 150. Parts repaired, 2,300,000. Parts manufactured, 1,050,000.	—	550 vehicles.

TABLE 6.

Machine-Tools in M.T. Repair Shops, B.E.F.

Machine-Tools.	Repair Shop.				
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Drilling Machines . .	8	7	11	25	23
Furnaces and Ovens . .	3	1	3	4	4
Grinders	14	4	8	21	6
Power Hammers . . .	1	1	1	3	1
Lathes of various descriptions	34	38	28	88	31
Milling Machines. . .	2	3	3	22	5
Shapers and Planers . .	3	4	2	8	1
Presses	3	3	1	6	3
Power Saws. . . .	2	3	3	6	4
Screwing Machines . .	1	1	—	3	2
Slotting Machines . .	—	1	1	2	1
Various	—	4	—	13	3
Wood-working Machines .	4	5	5	10	5
Totals . . .	75	75	66	221	89

the General Meeting on the 19th November, I will confine myself to a few examples :—

At Zuytpeene there was a pumping-station fitted with mechanical filtration. The water came from a stream close by and was anything but tempting. The pumping-engine was of the Dennis fire-engine type, with a Mather and Platt multi-disk centrifugal pump, capable of dealing with 120 gallons per minute against a head of 500 feet. The water was treated by a Wallis and Tiernan chlorine regulator working on the ferro-alumina principle.

At Hondeghem similar pumps were used, but the water was

delivered into an open reservoir, where the ferro-alumina was added, and thence it flowed by gravitation into a 9,000 gallon chlorinating tank. From this tank it was pumped into a reservoir some distance away from the camp.

Air-lifts were used to a large extent, and the water supply dealt with by them covered an area of 1,000 square miles. In March 1918 there were twenty-four stationary air-lifts at work. In some cases a portable air-compressor plant driven by a petrol engine was used, and it went from one well to another. One of the difficulties of these pumping plants was that they had to be continually removed and re-erected to meet retreats and advances.

An interesting well-pump was developed, originally of French design. An 8-inch loosely woven canvas belt, long enough to be immersed in the water of the well, ran over an 18-inch pulley, driven by a small petrol engine. On turning over the pulley, the water was driven off the belt by centrifugal force, and thus separated and caught.

530 engines, aggregating 4,150 h.p. were in use, mostly of small power, from 1 h.p. to 2 h.p., and there were forty sets of 60 b.h.p. There were nineteen kinds of pumping plants, capable of dealing with 1,000 to 4,000 gallons per hour, and one plant had a capacity of 12,000 gallons per hour, delivering against a 450-foot head. The numerous kinds of pumps caused considerable difficulty as regards repairs, but in course of time a certain amount of standardization took place which made the obtaining of spare parts easier.

Portable workshops were installed on barges, and I saw one of them at work in February 1919 on the repair of lock gates near Quinchy. Amongst the machinery was a shearing and punching machine, an 8-inch S.S.C. lathe, a 36-inch circular saw, a shaping machine, four Asquith drilling machines, a full outfit of pneumatic drills and hammers, and a self-contained concrete mixer.

Some idea of the volume of work can be gathered from the stores that had to be dealt with, as will be seen from Table 7 (page 1056).

TABLE 7.

Directorate of Transportation.

STORES dealt with during the month of July 1918.

Landed at French Ports	169,741 D.W. tons.
Channel Ferry :—	
To France	5,488 „ „
From France	890 „ „
Railways :—	
Loaded Wagons—Normal Gauge	24,866
Metre Gauge	2,287
Light Railways, 60 cm.	139,411 tons.
Roads, Mechanical Transport :—	
Total tonnage	84,516
Ton-miles	359,327
No. of Lorries	1,000
Quarries—worked by British :—	
Marquese Group	47,624 tons.
Other Quarries	19,448 „
Personnel for Railways, Roads, Docks, etc. :—	
Skilled	56,676
Unskilled	55,976
Total	112,652

The R.E. workshops require special notice. Some of these were more or less permanently sited during the War, and others were movable. They were divided into Army shops and Corps shops, and the following gives a few particulars :—

An R.E. workshop was established near the canal at Arques. It comprised a small foundry, a smithy with power-hammer and an outfit of medium size machine-tools.

At Vendroux there was a very extensive R.E. yard, with 70 miles of track, in order to deal with the storing, delivery, and distribution of timber of various scantlings, sandbags, barbed wire, duckboards, joists of various sections, small railway bridges and heavy bridging timbers, etc. The store-sheds were steel-framed buildings of

considerable height, 1,200 feet long and 120 feet wide. The workshops at the same place were of considerable extent. The foundry had a 10-, a 5-, and a 2½-ton cupola. The largest casting made weighed one ton. There were also a large machine-shop—electric motor driven—also an extensive wood-working shop. One shed was devoted to deal with guns on railway mountings, and a 150-ton Goliath crane was erected for this purpose.

Another large R.E. shop and stores were situated at Avancourt, and covered 683 acres. The articles stored were similar to those referred to above. The workshops were extensive, consisting of sawmills, joiners' shops, containing a large amount of wood-working machinery. From 400 to 600 trucks per day were loaded and unloaded. These shops were near a very large munition dump and stores. 100,000 tons of supplies of all kinds were kept. Half the original dump was blown up by the Germans on Whit Sunday and Whit Monday 1918, and 10,000 tons of ammunition were destroyed. No. 2 extension was then built, but No. 3, which was laid out, was never started.

The 352nd Electrical and Mechanical R.E. Company was established in December 1916 and co-ordinated all the work for obtaining and receiving stores, installing, operating, and for repairs of all R.E. machinery in the 3rd Army area. It also dealt with water supply, electric lighting, and workshops. This did not clash with the subsequently formed R.E. Mechanical Workshops, which only did repetition manufacture. There were similar companies in the other armies.

A review of the workshop situation, especially in the early years of the War, leaves the impression that there should have been greater co-ordination. At one time a suggestion was made that a Corps of Mechanical Engineers should be formed, but whether separate from the R.E.'s or affiliated thereto was, I think, not specified. An organization of this kind is, in my opinion, necessary to meet mechanical engineering requirements of war, but there are many difficult points to settle and many interests to be observed. In the event of such action being taken by the War Office, I am sure you will agree with me, that this Institution should do all in its power to

assist in the formation of any organization that might be sought to be established, and in particular in keeping a register of its members as to their qualification for the various duties comtemplated, so that the peace-time establishment could be rapidly enlarged to war requirements.

I now come to the work of the mechanical engineers at home.

As regards how and when mechanical engineers were mobilized for war work at home, it is only necessary to record the fact that on the motion of Mr. Lloyd George the Ministry of Munitions was formed in the first half of 1915, and under its control the various works in the country produced the munitions required of them, in addition to which the Ministry also constructed a large number of new works making shells, fuzes, aeroplanes, sulphuric acid, nitric acid, and explosives generally. The control was exercised in various ways, but broadly the country was divided into munition areas, each administered by a committee.

In a general way it may be said that munitions included almost every industry carried on in peace time, in addition to the purely naval or military requirements that are associated with Woolwich Arsenal and the armament firms. Many works were extended and new works were built to manufacture articles of ordinary use, but required in enormously greater quantities for the conduct of the War, as well as extensions and new works needed for articles peculiar to warfare.

One of the areas referred to above may be taken as an example, namely, the Metropolitan area, and I consider this one because I was a Member of its Committee.

The preliminary meeting took place in June 1915, and subsequently the Committee was received by Mr. Lloyd George when the general extent of its operations was settled, and Mr. Lloyd George promised all the financial support the Committee might require. A memorandum was prepared, which exactly defined the work to be undertaken, and practically the Committee undertook to supervise the work in the whole of the London area, but it was stipulated that it would in no way interfere with Woolwich,

or any of the firms already engaged in Government work. It was directed to secure the assistance of public utility services, and it was arranged that all raw materials should be purchased through the Government. Three Sub-Committees were appointed, namely, the Management Committee, the Census Committee, and the Financial Committee.

The Census Committee was discontinued so soon as the various works had been selected. In this connexion the total number of works inspected was 923, of which 355 were found suitable, and ultimately made munitions of various kinds to a greater or lesser extent. In addition to these existing works, new works were established, such as the Projectile Works at Staines, and a filling factory at Park Royal, which was of very considerable extent.*

The first and most pressing difficulty was in connexion with the production of gauges, which became so acute that a Sub-Committee was formed to deal with the matter. Dr. Unwin was Chairman of this Committee, and I would like here to record the value of the services he rendered on this occasion.

At that time the outcry was for shells, and the work of the Metropolitan Committee was practically concentrated on shells, on fuzes, and on gaines. The following statistics will give some idea of the work actually done by the Metropolitan Committee during its inception in June 1915 to June 1918, that is to say, in three years :—

TABLE 8.

Metropolitan Munitions Committee.

Total Output of certain items at 29th June 1918.

Shells	8,198,874
including :—	
18-Pounder High Explosive	1,766,599
9·2 High Explosive	128,659
6-inch High Explosive	377,560
4·5 „ „	1,322,744

* A slide showed the position of the works employed in the London area.

18-Pounder Shrapnel	1,514,224
3-inch Stokes	976,407
Grenades	798,449
Components	45,294,837
including:—	
Gaines	8,240,788
Adapters	11,631,848
Primers	13,718,456
Sundries	87,487,740
Gauges	247,051
Value of these articles and others not mentioned	£14,923,949

Early in 1917 a Department called the Munitions Works Board was established, whose duties were to examine, criticize, and authorize, any scheme put forward by a manufacturer for enlarging his Works, and for installing machinery for the production of munitions, and a further duty was to see that the work so authorized was duly carried out. Such a Department, although starting late, was obviously necessary because, owing to the shortage of materials, they had to be rationed in accordance with the importance of the work, and only a centralized Department could have the necessary information for such decisions. It is to be feared, however, that in many cases the time taken to obtain authority led to great delays and retarded supplies.

In 1915, in pursuance of the Defence of the Realm Act, powers were taken to control firms capable of producing munitions. Certain facilities were given to these firms to obtain labour and materials, and as regards finance, although in many cases assistance was given by the Government, the capital required for extensions to buildings and plant was provided by the firms themselves. The assets thus created would obviously have very varying values when no longer required to make munitions, and it was, therefore, provided that the firm should be reimbursed with that portion of this expenditure which represented the difference between the amount of the actual expenditure and the post-war value of the assets to the firm produced by this expenditure.

Strictly, the value could only be ascertained after the War,

but to wait until an unknown date to fix an unknown value was not an inviting prospect to capitalists or manufacturers. The apparently impossible task of predicting this value was undertaken and, with a view to inspiring confidence, an Honorary Advisory Committee was formed to deal with the matter. The first step in the formation of this Committee was taken by Mr. Basil Mott in December 1915, and the late Mr. Chatfeild Clarke, and it was ultimately composed of the following members :—

Chairman : Mr. Seager Berry.

Engineers : Mr. Basil Mott, C.B. ; Colonel Morgan, C.B.E. ; Captain Sankey.

Surveyors : Mr. Leslie Vigers ; Mr. Jonas, C.B.E. ; Mr. Head (the latter gentleman joined the Committee on the death of Mr. Chatfeild Clarke).

Originally this Committee was attached to the Ministry of Munitions, and later was transferred to the Board of Inland Revenue. Throughout, the Committee has been in an independent advisory position, a position which it jealously guarded, for otherwise it was felt that it would not be able to gain or maintain the confidence of both the Government and the controlled firms.

The Committee began its work in March of 1916, and it has still a few cases upon which to report. A set of rules was drawn up to regulate the method of ascertaining the residual or post-war value of the expenditure incurred for war purposes for the guidance of the staff of engineers and surveyors, and it was an invariable rule that every works should be visited, the smaller works by the staff and the larger ones by the members of the Committee, before any conclusion was arrived at. This rule was made because a study of the most complete list of items of plant, without seeing the items themselves and their relation to the pre-war plant of the firm, would be quite inadequate to form a fair opinion of the value—at best an unintelligent guess would be made.

The Chief of the Staff was Colonel P. W. D'Alton, *Member*, and I would like to take this opportunity of expressing my own personal

appreciation, which I know is shared by the Committee, of the excellent services he has rendered. He has helped me materially in getting information for this part of my Address, and has enlisted the services of several of his friends. I am very sorry that, owing to the exigencies of time, I have only been able to use a small portion of this information.

The heads of the firms, recognizing that the Committee was not a body of Government officials, but were giving their services in an honorary capacity, supplied to the Committee quite openly private information which greatly assisted in arriving at a true and fair value of the post-war assets, and there can be no doubt that this confidence quickened the faith of the manufacturers in their Governmental employers, and by stimulating the patriotic energy which was so marked a characteristic of these manufacturers, helped to raise the output of munitions to the satisfactory pitch which it eventually attained.

The great variety of the production of the works valued by the Committee, and the scope of its work, will be realized from the following three lists :—

TABLE 9.

Pig Iron. C.I. castings.
Steel ingots, forgings, stampings and castings.
Steel sections and bars.
Shell billets.
Copper Ingots and all kinds of alloys.
Tungsten powder and Ferro-tungsten.
Machine tools of all kinds—Hydraulic presses, steam-hammers, cranes and travellers.
Metal Sheets, tubes of steel and copper—all sizes. Wire rope and wire netting.
Boilers—Steam-engines (land and marine).
Oil and Gas Engines—Gas Producers.
Optical and Scientific Instruments.
Guns of all calibres, Howitzers and Bomb throwers—Rifles, Lewis and Machine Guns.
Shells of all calibres and in all stages of manufacture, gaines, fuzes and component parts.

Shell filling.
Mines, hand-grenades, bombs, torpedoes, cartridge cases.
Bayonets.
Explosives of all kinds—Sulphur. Nitric and other acids. Poison gases.
Chemicals—Dyes.
Ships of all sizes, both naval and mercantile.
Motor Vehicles and their component parts, such as chassis, engines, etc.
Tanks and their components.
Aircraft and their components, such as engines, fusilage, frame-work, fabrics.

TABLE 10.

Abstract from the Records of Works inspected by the Valuation Committee.

Kind of Munition.	Number of Towns in which the Works were situated.	Districts in which the greatest capital expenditure for extensions of Works occurred.	Total Capital expended in Extensions.
			£
Shells.	76	Yorkshire, Lancashire, Midlands, London.	3,500,000
Explosives and Poison Gases.	44	Yorkshire, Lancashire and Cheshire, Scotland, Midlands.	7,880,000
Guns and their Mountings.	47	Midlands, Eastern.	950,000
Aeroplanes, Seaplanes, Flying Boats.	31	London, Midlands, Eastern.	1,130,000
Aeroplane Engines.	17	Midlands, London District.	2,300,000
Tanks and their Components.	17	Midlands.	390,000
Steel.	41	Yorkshire, Wales, Scotland.	4,650,000

The above is only a part of the Capital Expenditure on Works Extension, as it does not include Armament Firms or National Factories.

TABLE 11.

Valuation Committee.

I. Number of Companies whose establishments have been inspected by the Committee or their Staff.

	No.
(*a*) Spending more than £1,000,000 on Buildings and Plant	8
(*b*) „ between £500,000 and £1,000,000	12
(*c*) „ „ £100,000 and £500,000	90
(*d*) „ „ £20,000 and £100,000	319
(*e*) „ less than £20,000	726
Total	1,155

II. Locality. Number of Controlled Establishments dealt with in the following districts:—

	No.
Scotland	156
Northern	269
Midland	461
Southern	39
Eastern	39
London	160
Ireland	3
Wales	28
Total	1,155

III. Total expenditure on Plant considered by Committee	£54,876,108
„ „ „ Buildings „ „	£27,096,743
Total	£81,972,851

The extensions made to works can be divided into three broad categories, as affecting post-war values, namely:—

Group 1.—Merely an extension of the ordinary work of the firm, such as the making of machine-tools in larger quantities and in larger sizes, hydraulic presses of the ordinary kind and of special kinds, motor lorries, tubes of many kinds. In such cases the expenditure incurred would be of post-war benefit to the company and hence to the country. On the other hand, plant for largely increasing the

making of glycerine at soap works or for enormous increase in small-arm ammunition manufacture would have little post-war value. Sometimes, although the extensions were in conformity with the pre-war intentions of the firm, they had to be modified in execution owing to war exigencies, and would therefore have a reduced post-war value.

The manufacture of steel helmets is an interesting case of the application of existing processes to war purpose. I am indebted to Messrs. Joseph Sankey for the following account of the difficulties encountered and final success.

"When the War Office decided to use bullet-proof steel for helmets there were many practical difficulties to be overcome.

"The manganese steel (and nickel steel) from which the helmets were made, was extremely difficult material to press and varied very greatly in quality. The percentage of breakages in the first experiments was so great that it seemed at one time doubtful if quantity production could be proceeded with.

"The steel sheets were produced by Messrs. Beardmore, Firth and Hadfield, and the closest co-operation was secured between these suppliers and ourselves so that the cause of breakages was scientifically investigated, with the result that the percentage of waste was gradually reduced from 50 per cent to an average of less than 5 per cent. In other words, material, the composition and treatment of which appeared to make it unsuitable for being worked by pressing, was ultimately found to be capable of being worked and pressed into a deep bowl-shaped helmet with as small a percentage of waste as would be possible with soft steel of ordinary commercial quality.

Production commenced in October 1915 at these works. The initial output arranged for was 5,000 per week. The weekly output was gradually increased up to 75,000 per week. Nearly 5,000,000 helmets were ultimately supplied to the Trench Warfare Department from our works."

Group 2.—Work of a similar nature to pre-war work, but so modified for war purposes that the plant required would not be useful post-war. Examples are given in the following list :—

TABLE 12.

GROUP II.

Similar Production.

WAR.	PRE-WAR.
Forgings for shell presses.	Colliery winding engine forgings.
Steel for shell billets.	Steel for tinplate billets.
Steel tubing for aircraft.	Steel tubing.
Springs for guns.	Springs for railways.
Machine gun belts.	Penmakers.
Howitzer parts forgings.	Crank-shaft forgings.
Filling hand grenades.	Fireworks.
Trench howitzer bombs.	Castings.
Smoke producing appliances.	Fireworks.
Fuzes.	General brass founders.
,,	Gas water and electric fittings.
Casting cartridge metal.	Artistic metal work.
Repairing brass cartridge cases.	Brass stampings.
Castings for hand grenades.	Light castings for building trade.
Trench warfare munitions.	Railway, ship and tramcar fittings.
Plant for explosives.	Plant for chemical works.
Glycerine and explosives.	Dyes and chemicals.
Cordite incorporating machines.	Baker's machinery.
Destroyers—Submarines.	Cross-Channel steamers.
Pontoon wagons.	Railway wagons.
Aeroplane engines.	Motor-car engines.

Group 3.—Entirely different work* to that carried out in peace time by the firm, as shown in the following Table :—

TABLE 13.

GROUP III.

Dissimilar Production.

WAR.	PRE-WAR.
Guns.	Motor-cars.
Gun carriage details.	Sluice valves and hydrants.

* Several slides were shown illustrating munition work, kindly supplied by Mr. Cribb, of Messrs. Marshall and Sons, Gainsborough.

War.	Pre-War.
Shells.	Almost every kind of works.
6-inch shells.	House decoration.
9·2-inch shells.	Rubber-making machinery.
Fuze bodies.	Electric cables.
Fuzes and gaines.	Motor-cars.
Mines, fuzes, hand-grenades.	Incandescent electric lamps.
Electric contact mines.	Heating and ventilating.
Bomb heads and lathes.	Domestic mangles.
Hand grenades.	Mach. for preparation of food.
Howitzer bombs—mine sinkers.	Rubber-making machinery.
Plant for explosive works.	Paper-making machinery.
Explosives.	Constructional steel.
Aeroplane parts.	Textile machinery.
,, ,,	Printer's machinery.
Rotary aeroplane engines.	Centrifugal pumps.
Marine engines.	Dynamos.

It is certain that most firms did not realize at first the extreme difficulty of manufacturing munitions of war. Generally the materials used have to be of exceptional quality, and are often difficult to machine ; and the degree of accuracy needed is far greater than is usual. Taking shells as an example, the steel has to be of a special hard quality to resist the blow of the charge on firing. It was, therefore, difficult to make in the first instance, except by armament firms, and until steel-makers had obtained the necessary experience, the outputs were low. After a time, however, the great demand for one particular steel leading to the constant running of the plant resulted in increased outputs. The cogging and rolling was also rendered more difficult, and much had to be learnt. Owing to want of skilled labour and deferred repairs, it was no easy matter to keep the plant running at full output.

It is interesting to point out that, owing to the assistance given by the Ministry to individual firms, this country is in a far better position than it was before the War as regards plant for steel-making and for forging. Capital approaching £15,000,000 has been spent in forging plant, such as hydraulic presses, furnaces, gas-producers, waste-heat boilers, and heat treatment plant, and the buildings to house the plant.

Even the apparently simple process of breaking the rolled bars into shell billets gave much trouble, and unless special care and trouble were taken, the billets did not break straight across, giving subsequently much trouble in piercing. The next stage—the piercing of the billet—was found to be a difficult operation. The piercer was apt to wander and much scrap was thus produced. The machining of the steel was quite different to what most workmen had been accustomed. The hardening of the tools and the rate of cutting were outside the usual experience of the workmen. The tolerances were small because any shell had to fit accurately any gun of the same calibre. Added to this the weight had to be kept within very small limits to ensure accuracy in range. A very difficult operation was the fitting of the base-plate necessary to prevent a "premature" in the event of even the smallest flaw in the base of the shell.

Difficulties of a similar nature were encountered in the manufacture of many of the munitions required for artillery, and it is a matter for great congratulation that our manufacturers, on the management and operative sides, rose to the occasion and produced work of the necessary quality and in the necessary quantity.

I cannot help remarking that many of these troubles should never have existed, and that consequently munitions in sufficient quantities would have been ready at an earlier date, had more foresight been exercised so that arrangements would have been made for instruction, in times of peace, of certain selected firms and workmen in the making of such munitions of war. Further, an adequate stock of gauges should have been kept. It would be interesting to know what has become of all the gauges that were made, and whether they have been properly stored and identified for future use.

A very serious cause of delay and unnecessary expense was the fact that the control of mechanical engineering operations was not placed in the hands of competent and experienced mechanical engineers, but in that of men of other professions, whose training prevented them from realizing the issue involved. In many cases the mechanical engineer had to educate his superior in office.

At first, for obvious reasons, makeshift had to be adopted with

the machine-tools available ; then special attachments were applied, and as time went on, many single-purpose machines were brought into operation, especially in connexion with shell-making. Of the many makeshifts, I have selected two. Ordinary power-driven planing machines were used for piercing shell-billets by fixing to the ends of the moving table one or more rams which pierced the billets in containers bolted to the base of the planers. Many millions of shells were produced in this way.

In the case of small calibre guns, the tubes and jackets were rolled instead of forged, thus relieving the forging presses and producing equally good results.

Great ingenuity was displayed in the design of jigs and fixtures, and much of the success attained by Messrs. Babcock and Willcox, for instance, in turning out large numbers of shells and bombs of many types and sizes (from 3 inches to 13·5 inches) is due to applying such fixtures to machines of a universal type. By their use unskilled labour could be employed and outputs were obtained which previously would not have been deemed possible, and on one occasion as much as 80 tons of cuttings were removed by thirty-four machines in one week.

Many of these special machines were new designs altogether, evolved to meet the conditions of rapid and accurate manufacture of shells, for instance, or their component parts. A series of special small bench machines, designed by Messrs. Samuel Platt for making "gaines," form a striking example. These machines, costing £17,000, turned out 250,000 "gaines" per week. The ordinary capstan lathes usually employed for this purpose would have cost £340,000 for the same output per week.

In other cases, as, for example, bullet-making machinery, it was only necessary to reproduce the special machinery already in use ; the number of such machines required was, however, very large, owing to the enormous increase in the demand. These machines cost about £100 each, and formed an interesting case of residual value, which was that of the scrap, worth about £1.

Special vertical hydraulic presses were employed for piercing the blanks for shells by the Erard process. These presses are of

quite special dimensions, that is, the columns are very close together in relation to the power of the press. They are, therefore, not at all suited for general work, and were regarded as of scrap value for post-war purposes. The same remark applies to presses used for drawing gun-cartridges.

The enormous number of the same thing that had to be made, combined with the accuracy required, imposed what are called "methods of interchangeability" and "mass production," and it cannot be doubted that many works have found out by practical experience the advantages of such methods as regards cost of production. It may, also, be said broadly that many firms in this country have learned to appreciate the difficulties and the advantages of the use of gauges, jigs and templates, standardization and interchangeable manufacture of parts.

The experience gained by steelmakers in producing enormous quantities of shell bar steel of a quality much superior to the ordinary structural steel will induce them to pay greater regard to the finishing conditions in steel-making.

Although we have had an Engineering Standards Committee for many years, it may be doubted if the true meaning of standardization was perfectly understood by those responsible for the conduct of many engineering firms in this country, although such methods had been adopted long ago for the manufacture of sewing machines, rifles, and the Willans engine. The necessities of the War have been a great teacher in this matter and this is a legacy for which we ought to be thankful, and it is much to be hoped that the lesson thus taught shall not be forgotten. It is believed that many firms who, before undertaking shell work had no definite limit system, have now adopted this, and are finding great benefits therefrom.

The establishment of standard designs requires greater care and thought than that necessary to make a non-standard design, and this is probably one of the causes that has made manufacturers hesitate and reject such methods. Now that they have been forced to use such methods by the exigencies of war, they will have realized their advantages.

One of the important matters entrusted to the Valuation

Committee was to settle what increase in depreciation of plant and machine-tools should be allowed in order to take account of the effect of war conditions. For this purpose visits were made to several machine-tool works, and a recommendation was drawn up, which was subsequently embodied in the regulations. The depreciation was increased for several reasons, such as the employment of unskilled labour, and longer hours the machine-tools were at work, the constancy of the operation carried out by any particular tool, resulting in local wear, as, for example, in the bed of a lathe.

So far, my remarks in connexion with the Valuation Committee have had reference to plant only, but the buildings erected to accommodate the extensions of plant had also to be examined to determine their post-war value to the owner. Many of these buildings were temporary structures, but a large number were of a more or less permanent character, and ought to find useful application in various directions. Construction was much hampered by the difficulty in getting steel and wood. Ferro-concrete was substituted in some cases, and even the roof made of this material. Aeroplane construction required very large shops, with an unusual amount of free space, necessitating roofs of large span, from 80 to 100 feet, which added to the cost of such buildings without increasing the post-war value.

The welfare of the workers was early taken into consideration, and the matter was administered by the Welfare Department established by the Ministry of Munitions, for the purpose of ensuring, as far as possible, the comfort of the workers. The erection of the necessary buildings, the provision of appliances and the running of the canteens was carried out by the respective firms, the Ministry assisting by a substantial grant of capital.

Undoubtedly the establishment of canteens was mainly due to the employment of women in such large numbers, and provision of this kind was imperative in their case. Now that the employment of women has more or less ceased, there must be large superfluous canteen accommodation, but it is to be hoped that the improvement in the amenities of the workmen's lives, which in some cases had

been provided by far-seeing employers long prior to the War, will now become of permanent institution with all.

The common cause, and the facing together of danger by all ranks of society, gave many the hope that after the War better relations would exist between masters and men, employers and employees, but from the present outlook it is obvious that such a hope is not to be fulfilled at present; in fact, the gulf is wider than ever. It may be that the long duration of the War obliterated these good influences, and that they have been replaced by malign influences. Cannot we hope, however, that the good seed sown in the early days of the War may yet germinate and eventually lead to the desired end, so that with the improved methods of manufacture and the better machinery now available, with good-will, mutual confidence and team work of all ranks in the works, an era of prosperity may shortly dawn in this country?

This leads to the consideration of the human element in industry, and I wish to call attention to the Paper on the subject by Mr. Ramsay at the Lincoln Summer Meeting. Hitherto this Institution has refrained from dealing with subjects other than of technical interest, except a Paper by Miss Monkhouse on "The Employment of Women during the War," and a Paper by Ben H. Morgan on "The Efficient Utilization of Labour in Engineering Factories." In my view the innovation is most desirable, and I feel that the Institution has a great field of usefulness in this respect, but inasmuch as the Council has decided that a Special Meeting is to be held in London on the 3rd December, to be followed, it may be hoped, by Local Meetings, to discuss Mr. Ramsay's Paper, I will refrain from further remarks, only urging the importance of the subject.

I feel that what I have said, confined as it has been to my own experience, and hence the most important Works are not even referred to, describes very inadequately the work done by mechanical engineers during the War; but I hope that I have been able to show that the services they were capable of rendering were not recognized by the Authorities until the end of the second year of the War.

The mechanical engineers are not altogether free from blame

in this matter, because they have not asserted themselves sufficiently and have not let the public know what their capabilities are. In my opinion this Institution should bestir itself to correct this state of things. To read and discuss Papers, and to promote various social functions, such as Summer Meetings, Annual Dinners and Conversaziones, should not constitute the whole of its activities. I look forward to the time when this Institution will render far more useful services to the community and, together with the other Engineering Institutions, will seriously consider the ways and means of showing to the public that modern civilization is entirely dependent on engineering, using the term in its broadest sense. If engineering is not the noblest, it is, at any rate, one of the noblest professions. Unfortunately it is not so recognized by the public in general, much to the disadvantage of the country.

Vote of Thanks.

Sir John Dewrance, K.B.E. (Member of Council), said that the applause with which the President's Address had been received rather suggested that the duty which had been allotted to him was wholly unnecessary, but, in accordance with precedent, he rose to propose that a very hearty vote of thanks be accorded to the President for the admirable Address he had just delivered. Perhaps some of those who stayed at home during the War might think that their particular activities were not sufficiently mentioned or dwelt upon in the Presidential Address; and there might be some who were actively engaged in the war area who thought that mechanical engineering, in some directions, did not receive as important recognition as they would have liked it to have had. He thought, however, that all the members would agree that the President, in an impartial manner, had given a very admirable and interesting review of the work that mechanical engineers had performed in the great victory for civilization which the Allies had so recently won. He looked upon the Address as

being a most useful historical account of the subject with which it dealt, and he thought it was only right that the Institution should put on record information which could only be obtained through the President having the opportunity of obtaining many facts and figures which did not come within the reach of the ordinary member. It afforded him the greatest pleasure to propose a most hearty vote of thanks to the President for the Address he had given.

Mr. L. A. Legros, O.B.E., said it afforded him very great pleasure to second the Resolution, because none of the members could appreciate so well as he could, having spent nearly a fortnight with Captain Sankey recently when he was completing his Address, the enormous difficulty he had had in deciding what to retain out of the immense amount of information that had been placed before him. It was a much more difficult matter for the President to decide what to keep than what to throw away.

The Resolution was then put to the Meeting by Sir John Dewrance and carried by acclamation.

The President thanked the Members very much indeed for their kindness in according him such a hearty vote of thanks, and for the way in which they had listened to his rather long discourse.

THOMAS HAWKSLEY LECTURE.*

LIMIT GAUGING.

By Sir RICHARD T. GLAZEBROOK, K.C.B., Sc.D., F.R.S.,
Hon. Life Member.

Captain H. Riall Sankey, C.B., C.B.E., R.E., ret., *President*, in the Chair.

Friday, 5th November 1920.

The fundamental principle involved in the use of limit gauges is now so well established that it is not necessary to do more than refer to it. To secure interchangeability and the proper functioning of the parts of a machine, particularly when manufactured in large quantities, each of those parts is made so that the dimensions on which its proper working depends lie within certain previously determined limits defined by two gauges—one of which, the go gauge, accepts the work, while the other—the not-go gauge—will not enter or will not allow the work to enter, as the case may be; the difference in dimensions between these gauges gives the tolerance permitted to the manufacturer in order to tolerate inevitable errors of workmanship. The dimensions of the gauges fix the limits. The amount of this tolerance depends on the nature of the work and the purposes to be served by the part. For ease of manufacture, it should be large; to secure the accurate fitting and functioning, specially of the smaller parts of fine mechanism, the tolerance must

* *First* THOMAS HAWKSLEY *Lecture*, by E. B. Ellington, Proceedings I.Mech.E., 1913, page 1215. *Second Lecture*, by W. B. Bryan, 1914, page 811. *Third Lecture*, by Dugald Clerk, D.Sc., F.R.S., 1915, page 591. *Fourth Lecture*, by Harry E. Jones, 1916, page 631. *Fifth Lecture*, by Captain H. Riall Sankey, C.B., R.E. (ret.), 1917, page 703. *Sixth Lecture*, by W. Cawthorne Unwin, LL.D., F.R.S., 1918, page 405.

be reduced, and it is the work of the designer to select a happy mean between these two requirements. In this he may be greatly aided by careful specifications drawn up by some competent authority.

In this connexion, let me quote from an admirable memorandum recently prepared by Lieut.-Col. E. C. Peck, of the United States Army, for the use of a Commission on Screw Gauging now at work in America. Colonel Peck writes :—

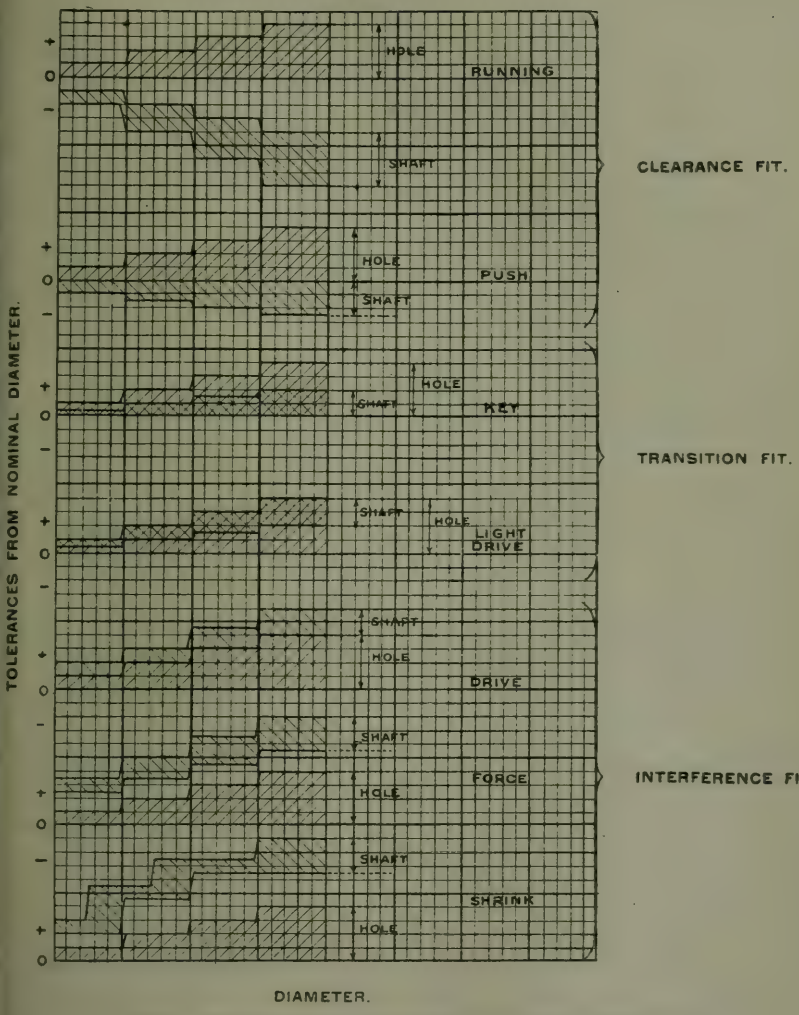
"Successful manufacture of a good quality of a product at a low cost requires skill, ability and experience of a high order, and in every successful enterprise there is one man or more who has these qualifications. It is then necessary to transfer his skill ability, and experience to the various workmen and embody it into the manufacturing methods. Proper manufacturing methods accompanied by a good system of gauging have been found an admirable method of transferring the skill of a single good man to an entire organization. As every operation of manufacture is given study and consideration, the gauging is taken into account at the same time, and that method chosen which is best from both standpoints. This will bring about a condition in which every operation shares in the skill and ability of this competent man. Then, with the proper training of the workmen, interchangeable manufacture becomes an economical and satisfactory process."

One of the Committees of the British Engineering Standards Association has recently given much attention to the question of limit gauging, and a Paper by Mr. A. A. Remington, from which I have permission to quote, lays down the principles of the matter and the requirements of a standard system in a very admirable manner. I propose, therefore, to state some of his conclusions and then to discuss how to reach these in practice.

Limit gauging may be applied to many kinds of fit and to the various parts of a mechanism. There are two classes of work, however, to which it is specially applicable: (1) The fit of a shaft (usually circular in section) in a hole (usually cylindrical), and (2) the fit of screwed bolts or studs and nuts. I propose to deal in the

FIG. 1.

DIAGRAM OF GRADES OF FIT.



NOTE.—*Minimum Hole is assumed to be Nominal Diameter.*

(Reduced from B.E.S.A. Memorandum, C.L.(M.) 6884.)

main with these two, though the principles discussed may readily be extended to other kinds of fit.

The fits considered may be divided roughly into three classes, described as (*a*) Clearance fits, when there is a positive allowance between the largest possible shaft and the smallest hole; (*b*) Interference fits, when there is a negative allowance between the largest hole and the smallest shaft, that is, when the shaft is always larger than the hole; (*c*) Transition fits, covering all cases between (*a*) and (*b*)—(i.) When the largest shaft is coincident with the smallest hole; (ii.) When the smallest shaft is coincident with the largest hole.

Fig. 1, taken from Mr. Remington's Paper, gives the nomenclature suitable for a series of such fits which, as pointed out by Mr. Dumas in a valuable Memorandum contributed to the British Engineering Standards Association, may be grouped thus :—

Clearance fits	—Running fits.
	—Push fits.
Transition fits	—Key fits.
	—Light drive fits.
Interference fits	—Drive fits.
	—Force fits.
	—Shrink fits.

The running fits will need still further subdivision, and there will be a number of grades of fit required to suit various classes of work.

In dealing with the matter more in detail it will be well to bear in mind the following definitions adopted some years ago by the Engineering Standards Committee:—*Tolerance* *: A difference of dimensions prescribed in order to tolerate unavoidable imperfections of workmanship. *Allowance* †: A difference of dimensions prescribed in order to allow various qualities of fit. Again, following Mr. Remington, we may state that the tightest fit permitted in these various cases is as follows :—

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* On this matter, *see* later in the Lecture.

† As already pointed out, a negative allowance is an interference, or obstruction.

(*a*) *Clearance fits.*—The tightest fit (given by the minimum allowance) must be such as to provide proper lubrication and absence of seizure under service conditions.

(*b*) *Transition fits.*—The tightest fit must allow of the parts being assembled and taken apart without difficulty or damage.

(*c*) *Interference fits.*—The tightest fit must be such as to permit of the parts being assembled without seizure or breakage.

While for the slackest fit we have the following requirements :—

(*a*) *Clearance fits.*—The limits must be such as to leave as large a margin for wear as practicable. The fit will be slackest when the maximum allowance, which will function properly, exists, that is, when the parts are on the point of being worn out.

(*b*) *Transition fits.*—The limits must be such as to ensure proper registration and restraint of relative movement of the elements paired, having regard to the purpose for which they are used.

(*c*) *Interference fits.*—The limits must be such as to ensure a proper grip between the elements and absence of slip under service conditions. To secure this, the allowance between the largest hole and the smallest shaft must be negative : the shaft must be bigger than the hole.

In all cases in which the parts are in relative motion when the machine is in use there is wear, and this wear tends to increase the difference of dimensions—the allowance—between the parts. Thus there are two reasons for prescribing a maximum and minimum allowance :—(1) In order to provide for wear ; (2) in order to provide a tolerance, to tolerate errors of manufacture. It is not therefore correct in such case to denote by the word "tolerance," as is often done, the difference between the maximum and minimum allowance. Part of that difference is prescribed in order to permit of wear, and the tolerances, as Mr. Remington points out, reduce the permissible wear and thus shorten the life of the parts.

He thus arrives at the conclusion that "a logical system should therefore provide the minimum allowance when minimum holes and maximum shafts are paired (and this should be the ideal as providing maximum life), and such tolerances on holes and shafts as

will facilitate manufacture and avoid scrap or undue cost of manufacture to the required extent without undue shortening of life on service. For inspection work the tolerance should be positive on the high gauge and negative on the low."

Accepting, then, these principles it remains to consider how they may be best applied to the various classes of work. It is clear that the same tolerances will not fit all classes of work. Optical instruments, small electrical apparatus, and the like are in a different class to machine-tools. These, again, differ from marine engineering and other heavy work, while structural work requires still larger tolerances.

At the outset we are met by an important question. We are to secure the various grades of fit by prescribing differences of dimensions between the shaft and the hole. Shall we provide those differences by varying the dimensions of the shaft or of the hole. In two parts of the same machine we have shafts each of about an inch in diameter, the one shaft is to rotate freely in its hole, the other is to be a push fit. Three alternatives lie before us :—

1. We may make the shafts alike, both being as nearly 1 inch as the conditions permit, and vary the holes. This is known as the shaft basis.

2. We may make the holes of the same size and vary the shafts. This is the hole basis.

3. We may vary both shaft and hole. This last alternative may be dismissed as introducing a quite unnecessary complication.

In their report on Limit Gauging, Report No. 25, issued by the Engineering Standards Committee in 1906, the first alternative, the shaft basis, was adopted, though it is clearly pointed out that the recommendations of the report apply, *mutatis mutandis*, to the hole basis; the report deals only with running fits. It is, perhaps, not necessary to discuss the reasons for the choice ; suffice it to say that, in the interval, conditions and methods of work have altered greatly, and now for most engineering work it is generally agreed that a hole basis is desirable. This view is, I think, accepted in America and abroad as well as by the industry in England.

Colonel R. Peck, whose valuable paper has already been quoted,

writes :—" As it is necessary to produce different amounts of looseness in different fits this must be done by varying the dimensions of either the external or the internal member "—that is, the hole or the shaft—" and it is made easier to do this on the external member, from a manufacturing standpoint, as all the processes for production are readily adjustable for size. As affected by gauges it is also easier, because these gauges are usually of the adjustable type or the work is measured by adjustable measuring devices. Increasing the tolerances on external members is obtained by adjusting both tools and gauges the required amount and proceeding without interruption."

Another reason may perhaps be added ; the diameter of the hole is usually taken as that of the plug-gauge which just fits it. I will return to this convention shortly. Most shops possess a number of plug-gauges, and the accuracy of these can be tested readily on a standard measuring machine. To measure to the same degree of accuracy the diameter of a ring-gauge is no easy task.

In describing, therefore, a system of limit gauging I shall assume the hole basis. But it must be realized that there are many instances —millwrighting is one—where a shaft basis is necessary. Shafting is drawn to definite sizes, usually with a small negative tolerance, and when it is desired to have various kinds of fit on the same shaft the allowances must be made on the hole ; any system must provide for this.

It should be noted here that the quantities which concern us are the allowance and the allowance plus the sum of the tolerances on hole and shaft. The allowance gives the minimum degree of play requisite for good working of the parts, the sum of the tolerances, the additional amount which can be permitted for errors of workmanship and wear. The tolerances can be divided between hole and shaft as thought best by the designer. This point of view has been well put by Mr. Dumas in his various communications to the Limit Gauges Committee of the B.E.S.A., and by Mr. Groocock of the B.T.H. in a Paper referred to later. In tabulating tolerances for a standard system, however, some division has to be agreed upon, and in view of the methods of manufacture, it is usual in the

case of the closer fits to assign one-third of the sum to the shaft and two-thirds to the hole.

The next step to consider is the amount of the tolerance permissible, or, rather, in the first place, its dependence on the diameter. Tolerance may clearly increase with the diameter, and investigation shows that a tolerance proportional to the square root of the diameter gives satisfactory results; to obviate the difficulty of having excessively small tolerances on small diameters, it is usual to prefix a small constant term and the formula—

$$\text{Tolerance} = a' + b'\sqrt{\text{D}}$$

has been very generally adopted, a' and b' being constants, and D the diameter.

A similar formula has been found suitable for the allowance in the case of running and transition fits. Lubrication space is provided thus in a satisfactory manner. In the case of interference fits—at least for the larger sizes—there appears some reason to suppose that the obstruction should be proportional to the diameter rather than to its square root, and in general we may say that the quantity with which we have to deal, whether tolerances or allowances, may be properly represented by the expression:

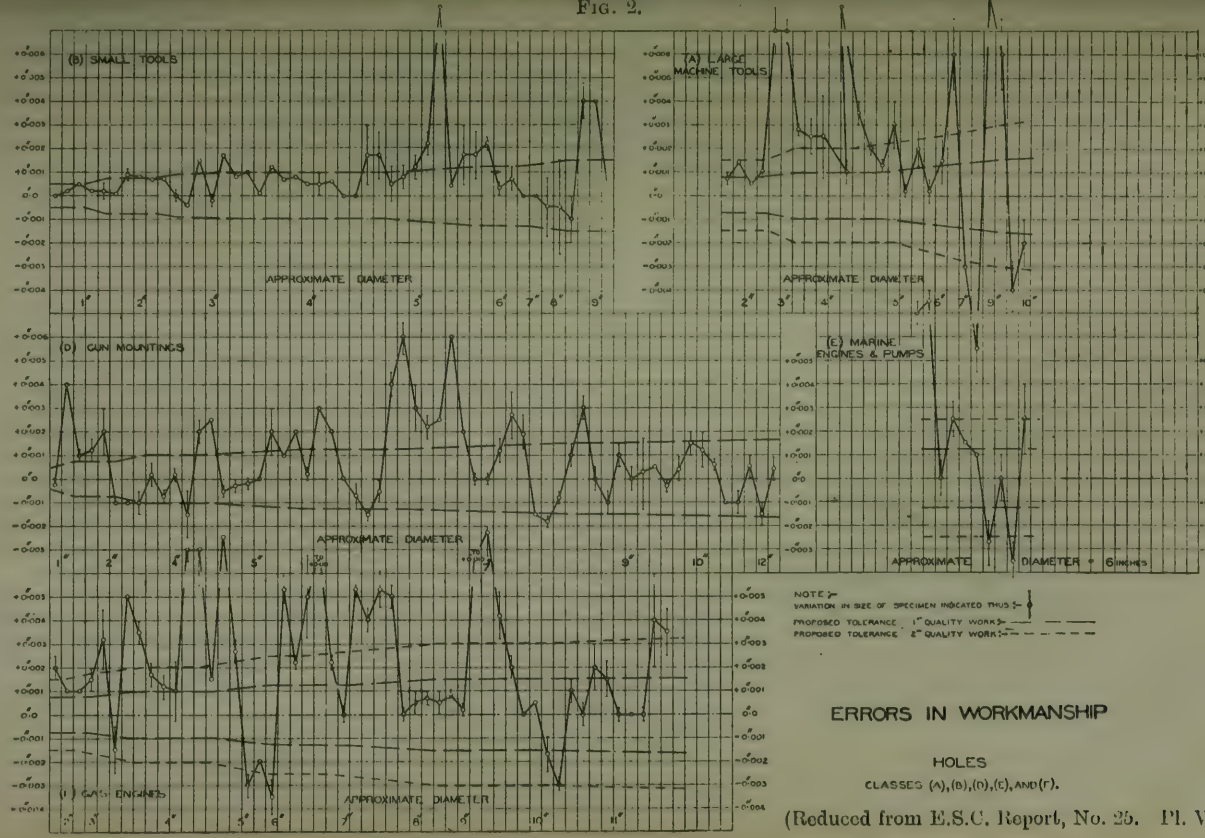
$$a + b\sqrt{\text{D}} + c\text{D},$$

a, b, and c being constants, any one of which may be zero, and D the diameter.

For some of the evidence on which this rests I would refer to Mr. Attwell's Report on Errors of Measurement (E.S.C. Reports, No. 25, July 1906), giving the results of his measurements on a large series of work in various shops. Figs. 2 and 3 are taken from that Report, and the results led the E.S.C. Committee to adopt the $\sqrt{\text{D}}$ law as shown in the chart appended to their Report No. 27, June 1906, British Standard Systems for Limit Gauges (Running Fits), Fig. 4.

The general approval of the $\sqrt{\text{D}}$ law is evidenced by the next figure, Fig. 5, which is due to Mr. Hedley Thomson, and which shows the tolerances on holes adopted in a number of systems of

FIG. 2.



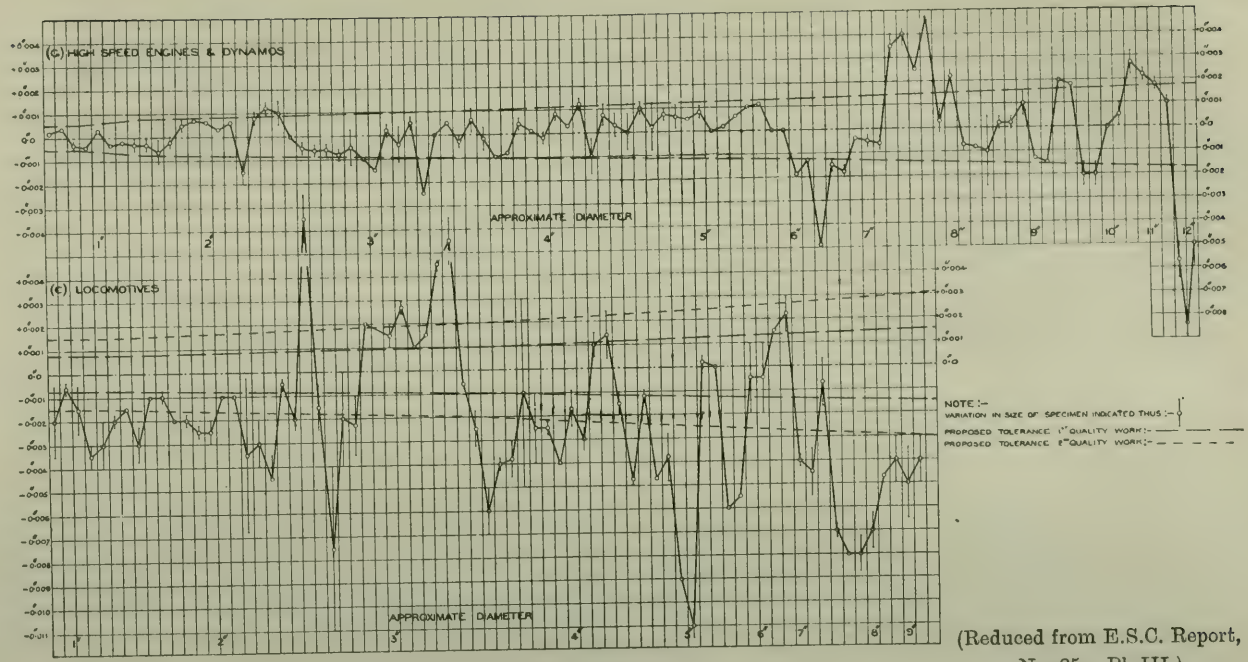
ERRORS IN WORKMANSHIP

HOLES

CLASSES (A), (B), (D), (E), AND (F).

(Reduced from E.S.C. Report, No. 25. Pl. VI.)

FIG. 3.


(G) HIGH SPEED ENGINES & DYNAMOS
APPROXIMATE DIAMETER
(C) LOCOMOTIVES
APPROXIMATE DIAMETER
NOTE :-
VARIATION IN SIZE OF SPECIMEN INDICATED THUS :-
PROPOSED TOLERANCE 1ST QUALITY WORK :-
PROPOSED TOLERANCE 2ND QUALITY WORK :-

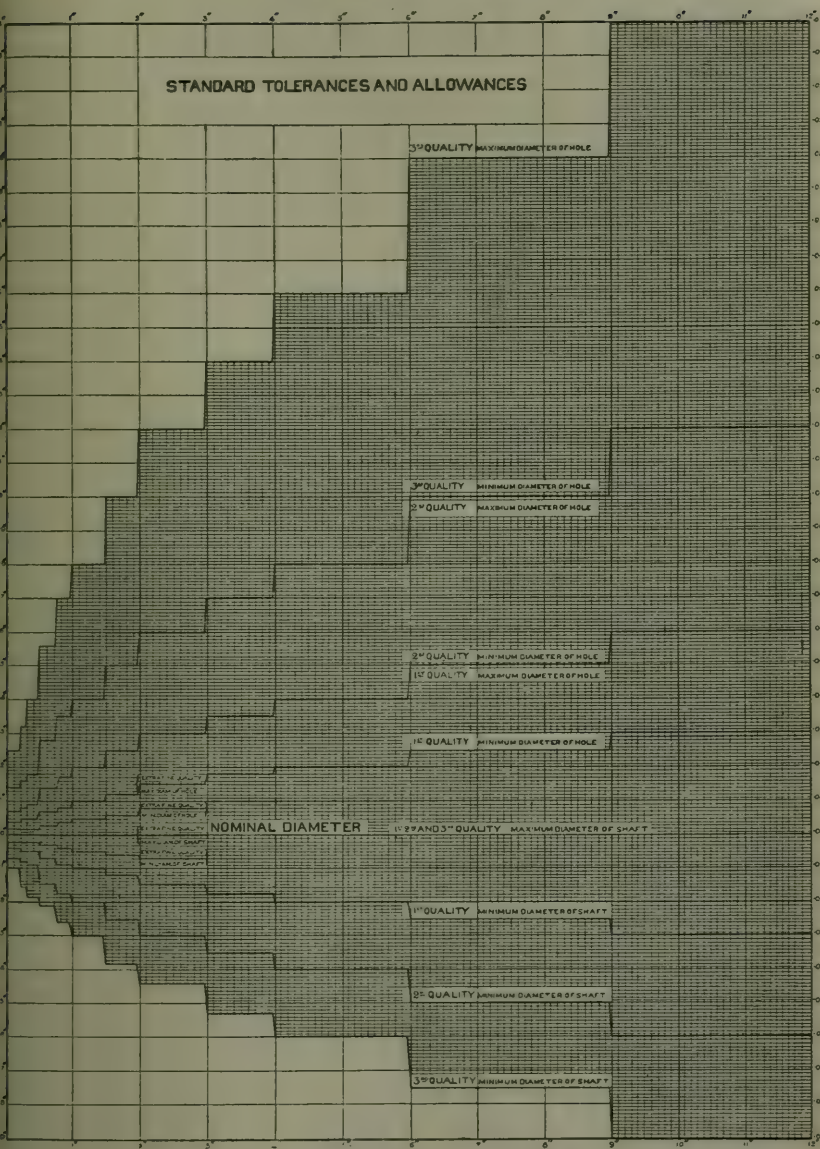
(Reduced from E.S.C. Report, No. 25. Pl. III.)

ERRORS IN WORKMANSHIP

SHAFTS

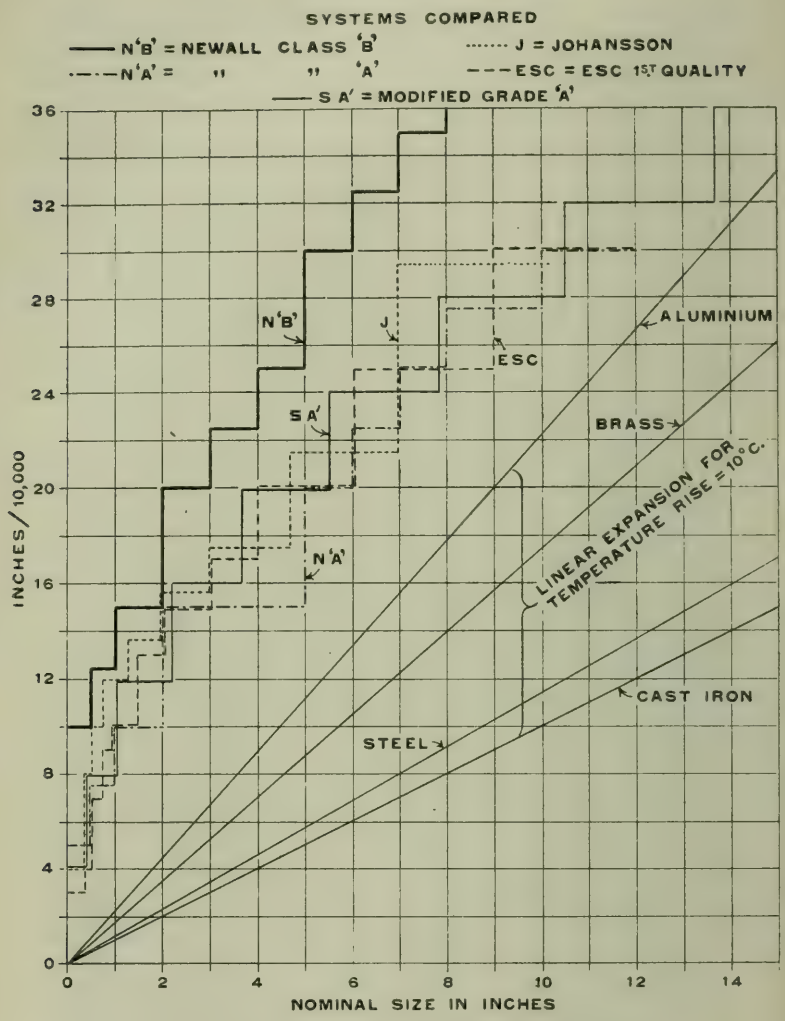
CLASSES (G) AND (C).

FIG. 4.—*Chart of Limits.*


STANDARD TOLERANCES AND ALLOWANCES
3rd QUALITY MAXIMUM DIAMETER OF HOLE
3rd QUALITY MINIMUM DIAMETER OF HOLE
2nd QUALITY MAXIMUM DIAMETER OF HOLE
2nd QUALITY MINIMUM DIAMETER OF HOLE
1st QUALITY MAXIMUM DIAMETER OF HOLE
1st QUALITY MINIMUM DIAMETER OF HOLE
NOMINAL DIAMETER
1st 2nd AND 3rd QUALITY MAXIMUM DIAMETER OF SHAFT
1st QUALITY MINIMUM DIAMETER OF SHAFT
2nd QUALITY MINIMUM DIAMETER OF SHAFT
3rd QUALITY MINIMUM DIAMETER OF SHAFT

(Reduced from E.S.C. Report, No. 27.)

FIG. 5.—*Limit Systems, Hole Tolerances.*



limit gauges, including those of Messrs. Newall, Johansson, Ludwig Lœwe, the E.S.C., and Mr. Hedley Thomson himself in his step system.

The diagram is interesting as indicating general agreement in

the amount of tolerance desirable. The curves for the linear expansion due to a rise of 10° C. should also be noted. In the case of aluminium a rise of 10° absorbs the whole of the tolerance on a 15-inch hole.

Before leaving this point, reference may also be made to an important paper by Dr. Kuhn ("Zeitscrift des Vereines deutscher Ingenieure") in which the $\sqrt{D}$ law is adopted. He states that tolerances and allowances based on $\sqrt[3]{D}$ and $\sqrt[4]{D}$ have been tried and found unsatisfactory. Thus, for the present, I assume the $a + b\sqrt{D}$ law. I will return to the interference fits later.

But it would clearly be inconvenient to have the tolerance varying with every small change in diameter; it is usual, therefore, in all systems to approximate to the parabola of theory—the curve that is given by the expression $(a + b\sqrt{D})$—by means of a series of steps.

Again, it is clearly convenient that these steps should be equal in amount; all the tolerances and allowances are then expressible in term of some common unit, and, by the aid of a set of Johansson slips or similar gauges, the shop gauges and the tools used in producing the work are readily adjusted to the required dimensions. As a unit step, the quantity 0·0004 inch has been found suitable, though in some cases a unit of half the amount or even, for very fine work, of one-fourth may be desirable. The quantity 0·0004 inch is practically 0·01 millimetre, so that a system in which it is the unit is easily adaptable to metric work.

An allowance of a given amount is applicable over a definite range of diameters, and Mr. Hedley Thomson pointed out that it follows as a property of the parabola that the allowances will increase at each step by the same quantity, provided the ranges are given by the series x, $2x$, $3x$, . . . nx where x is any suitable length.

A proof of this proposition and of some of the consequences which follow from it, is given in Appendix I.

It has also been suggested that a convenient system of ranges is given by the series when x is made equal to one-tenth of an inch. Thus the ranges will be, in inches, 0 to 0·1, 0·1 to 0·3. 0·3 to 0·6, 0·6 to 1·0, etc.

It is shown in the Appendix that in general in this case

$$n = \sqrt{\binom{2D}{x}} \text{ or } \sqrt{D} = n\sqrt{\frac{x}{2}}$$

An allowance or tolerance of the form $a + b\sqrt{D}$ thus becomes

$$\left\{a + b\ n\sqrt{\frac{x}{2}}\right\}$$

or as we may write it, making $x = \frac{1}{10}$ and choosing proper values for a and b—

$$0{\cdot}0001 \times r\ \{1 + n\} \text{ inch.}$$

Mr. Hedley Thomson calls r the range factor, n the range number, and $1 + n$ the range multiplier. The steps in this case are $0{\cdot}0001 \times r$ inch.

Another formula which is of value is that connecting n with the diameter and which enables us to find the range number n corresponding to any diameter D. It is (*see* Appendix I)

$$n\ (n + 1) > 20\ D \geqq (n - 1)(n).$$

Thus, given the diameter, in order to find the range number we have to find a quantity n such that $n\ (n + 1)$ is greater than 20 D, while $n\ (n - 1)$ is less than or equal to this same quantity. In practice, of course, a table of ranges would be used.

The actual steps depend on the value chosen for r; if it be thought in any case that they are too small, they can be increased by adding the ranges together according to some definite plan, taking two or three as the case may be to form new ranges. Thus, we might have as ranges 0 to 0·3, 0·3 to 1·0, etc., and the steps would be $0{\cdot}0002 \times r$.

A system somewhat similar to this has been suggested in Germany by Dr. Kuhn. He bases it on a quantity he denotes as a unit of fit given by the expression $\frac{1}{600}\sqrt{D}$ where D is measured in millimetres; if, instead of millimetres, we measure in inches, this becomes $\frac{1}{1500}\sqrt{D}$ or $0{\cdot}00066\sqrt{D}$.

For running and transition fits all tolerances and allowances are

expressed as multiples of this quantity and may be written as $k \times 0{\cdot}00066 \sqrt{D}$. This should be compared with the

$$0{\cdot}0001 \times r \times (n + 1)$$

of Mr. Hedley Thomson's system, remembering that the quantity n is proportional to $\sqrt{D}$, while his range-factor r corresponds to the k of Dr. Kuhn's formula. Mr. Hedley Thomson's small constant term does not appear in this.

The next step in the task of forming a system of limits would be to select the value of the constant r appropriate to the class of fit under consideration and draw a curve, or construct a table showing the tolerances corresponding to the various ranges of diameter. Thus, for the tolerances on a hole of ordinary good workmanship, 2 appears to be a suitable value for r and we thus get the following Table :—

TABLE I.

Standard Hole Tolerances.

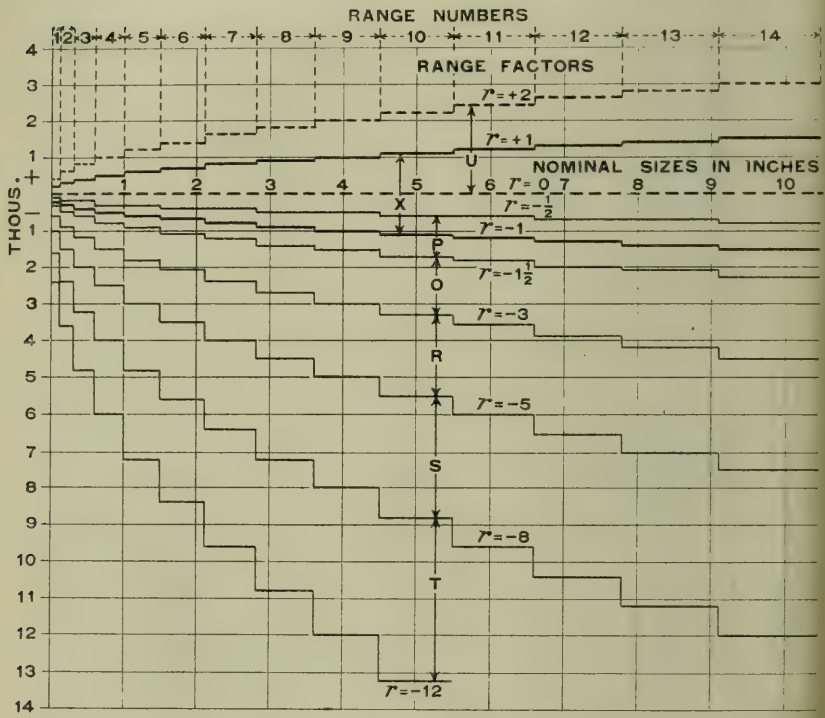
Range Factor 2.

Value of n Range Numbers.	Range.	Tolerance.
1	0·0 to 0·09	0·0004
2	0·1 „ 0·29	0·0006
3	0·3 „ 0·59	0·0008
4	0·6 „ 0·99	0·0010
5	1·0 „ 1·49	0·0012
6	1·5 „ 2·09	0·0014
7	2·1 „ 2·79	0·0016
8	2·8 „ 3·59	0·0018
9	3·6 „ 4·49	0·0020
10	4·5 „ 5·49	0·0022

If it be felt that the ranges are too short and the steps too numerous, we can combine ranges 1 and 2 with a tolerance of 0·0004, ranges 3 and 4 with a tolerance of 0·0008, and so on.

From the above Table all other tolerances and allowances can be calculated so soon as the suitable value of r, the range factor, is

Fig. 6.



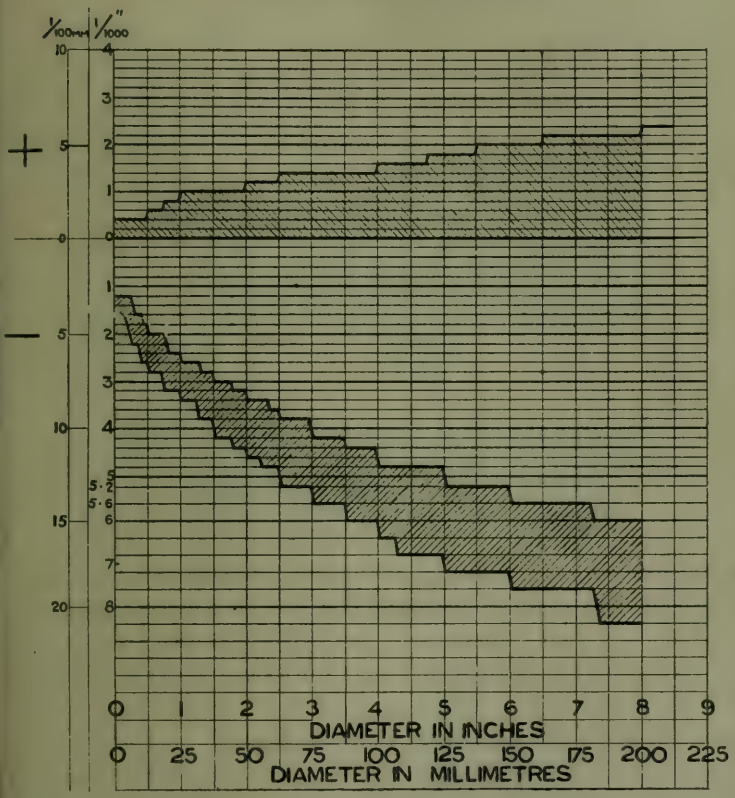
known, and the corresponding curves can be shown on a chart as in Figs. 6 and 7.

In such a chart the number of curves may be reduced, and the chart simplified by arranging, as can frequently be done, that a given curve serves for more than one purpose; for example it may represent the high limit for one class of fit and the low limit for

another. This is the case in Fig. 4 (page 1085), the E.S.C. chart, where the maximum diameter of the hole for first quality work is also the minimum diameter for second quality.

Such an arrangement enables the same gauges to be used as go gauges for one quality of work and not-go gauges for a better quality,

FIG. 7.—*Medium Running Fit.*

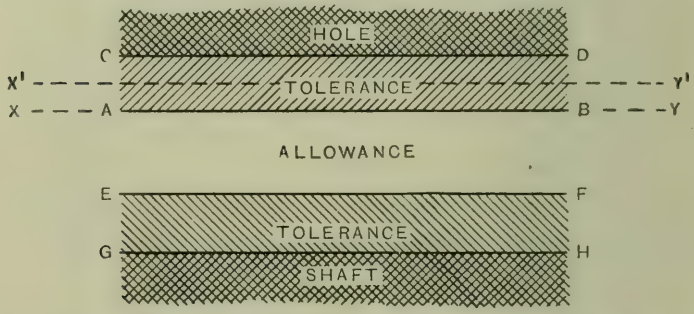


thus reducing the number of gauges required, and this in 1906 was held to be of importance. It also implies that the tolerance on the better class work is the difference between the allowances on two adjacent classes; thus introducing a restriction which may not always be desirable, while the argument based on the number of

gauges has lost weight since the introduction of the Johansson slips; it is probably only in few instances that the same gauge will prove suitable as a go gauge for one job and a not-go gauge for another. The relation of tolerance to allowance should be determined by reasons other than the simplification of a diagram or Table, and while there is some convenience in the practice, it should not be allowed to dominate the situation.

So far we have been dealing with matters about which there is now fairly general agreement among those who have given attention recently to the matter. We are on different ground when discussing the question which of the various dimensions we have been considering should approximate most closely to the nominal

FIG. 8.—*Minimum or Mean Hole.*



dimension of the piece. Taking, for example, the case of a running fit we have four lines to consider. Let Fig. 8 represent part of the section of a shaft running in a hole. AB represents the section of the surface of the smallest hole, and CD that of the largest hole. EF is a section of the largest shaft, GH of the smallest. The distance between AB and CD is the tolerance on the hole; that between EF and GH the tolerance on the shaft; while the distance between AB and EF measures the allowance. On this we are all agreed; moreover, these distances are small compared with the nominal dimensions of shaft or hole, and for many purposes it is not material where, in the diagram, we imagine the line XY, representing that nominal dimension, to fall, provided it is somewhere close to the four lines just drawn.

The Engineering Standards Committee in 1906, working to the shaft basis, laid it down that the nominal dimension was to be the maximum dimension of the shaft; and that this was to be the dividing line between shaft and holes. No shaft was to be larger than the nominal size, no hole was to be less. Interference fits and possibly certain transition fits would have formed an exception to this, but these were not dealt with in Report 27.

Their curves are equally applicable *mutatis mutandis* to the hole basis, as is pointed out in the report, and in this case the dividing line, the nominal dimension, becomes the minimum size of the hole; the tolerances on the hole are all positive; the allowance is made on the shaft, and both it and the shaft tolerance are negative. No hole is less than nominal; for running fits all shafts are less, allowance and tolerance both being negative. The nominal dimension or zero line XY would then coincide with AB, the line defining the minimum hole. This is known as the unilateral system.

But there is another school which considers it desirable to place the zero line somewhere between AB and CD, usually midway between them, as X^1 Y^1. In this plan, which may be called the bilateral system, the tolerance on the hole is both positive and negative, each of these being one-half of the total negative tolerance on the first or unilateral system.

There is, I think, a kind of feeling that the holes in this case will approximate more closely to their nominal dimensions and that there is some importance in this. I doubt if there is any real weight to be attached to either of these ideas; so long as the work falls within the assigned limits, its actual dimension is quite unimportant, while a careful workman making a hole will stop as soon as his plug gauge enters, as soon, that is, as the hole is just in excess of its nominal size on the unilateral system, and while it lies appreciably below nominal on the bilateral. If we take the values for the tolerance given in Table 1 (page 1089), then the total tolerance being 0·0012 inch on a hole nominally 1 inch in diameter, that hole on the unilateral plan will be between 1 inch and 1·0012 inch, while on the bilateral it will be between 0·9994 inch and 1·0006 inch. Either system can, no doubt, be made to work and—except for one

fact—the advantage seems to me, speaking, of course, in my private capacity, to rest entirely with the unilateral system; the one fact is that an important system of gauging now in use by a number of British firms is based on the bilateral plan.

On the unilateral system the knowledge that the nominal dimension forms a dividing line between hole and shaft affords a secure basis from which to start when designing a machine. The tabulated allowance on the shaft gives the least difference in dimensions between a shaft and a hole; the allowance plus the sum of the two tolerances gives the greatest, and these are the two facts one wishes to know when considering the action of the machine. On the bilateral system the minimum difference is less, being the shaft allowance minus half the total tolerance on the hole. Again, on the unilateral system the go gauge for the hole can be a standard gauge of nominal dimensions; this may prove a convenience to a firm possessing a set of standard gauges which is considering the question of adopting limit gauging.

Further, it should be noted that in America the Commission on Screw-Threads have just adopted the unilateral system, while on the Continent, though I believe the matter is still under discussion, the unilateral system seems likely to prevail; * Dr. Kuhn's system is based on it. On the other side there is to be set the difficulty of asking a number of firms to scrap their gauges and their system,

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* Since the above was written, definite information has been received. In reply to a questionnaire 65 per cent. of the Firms consulted expressed themselves in favour of the unilateral system, and it is added that, when the value of the votes has been established, there will be a considerable majority in its favour.

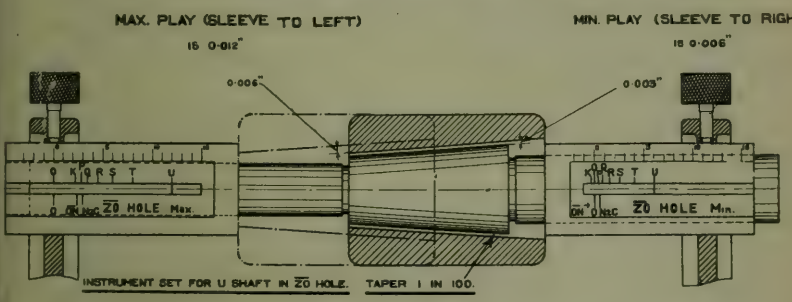
At a Meeting of the Standardization Board held to consider the position, all persons present expressed their agreement with the proposal that "The Standard Committee shall only publish the system of the Zero line as Standard line of Limits." The system of the Zero line is what has been denoted above as the Unilateral System.

The Firms present now using the Bilateral System promised to endeavour to introduce the Unilateral System, so long as no insurmountable difficulties were met with, and to report after an interval of two years as to whether they are in a position to adopt that system entirely.

if the unilateral system is the only one recognized as standard. The question has been very fully discussed by Mr. W. G. Groocock, of the B.T.H., in his Paper on Limits read before the Coventry Engineering Society in January last.* He measured a large number of pieces—shafts—made to varying tolerances, the work being produced both by grinding and turning. He found that while for small tolerances the full amount was required, in the case of by far the larger part of the work the average size lay much nearer the high limit than the low, and he shows in detail in his Paper that while this leads to considerable difficulties on the bilateral system, these difficulties hardly occur on the unilateral.

The difference of view has caused an unfortunate delay, at a critical time, in the revision of Report No. 27, and it may be well

FIG. 9.—*Hedley Thomson's Apparatus to Illustrate Fits.*



to devote some little consideration to it and to an ingenious proposal due to Mr. Hedley Thomson for getting over the difficulty, a proposal which I trust the Committee will adopt.

Put briefly, Mr. Hedley Thomson's suggestion made to meet this difficulty, is the standardization of a series of shafts which will pair equally well with either hole.

For running fits there would be rather more play with the unilateral hole than with the bilateral, the amount being measured by half the total tolerance on the hole. It is stated that except

* *Journal*, February 1920; *Engineering and Industrial Management*, — May 1920.

possibly for very fine work, the difference would be too small to be of serious import.

Thus, in the case of a normal running shaft 1 inch in diameter, the maximum and minimum sizes might suitably be 0·9982 inch and 0·9970 inch, giving a tolerance of 0·0012 inch. These sizes correspond with the values 3 and 5 for the range factor r. The limits for the inch hole are on the unilateral system one inch and 1·0012, and on the bilateral 0·9994 inch and 1·0006. Thus the values of the play lie between 0·0018 inch and 0·0042 inch unilateral and 0·0012 inch and 0·0036 inch bilateral. It is held that the difference 0·0006 inch in each case would in practice be negligible, and this view is supported by experiments with an ingenious piece of apparatus devised by Mr. Hedley Thomson and described in Appendix II. The apparatus consists of a shaft and a hole, each very slightly conical and of the same angle. By means of adjustable sleeves, the shaft can be inserted to a greater or less degree in the hole and the feel of a definite alteration in the clearance space between the two noted, Fig. 9.

For a transition fit, differences of the order noted above would be too large to permit a given shaft to be used for the same purpose, say, as a push fit, in the two systems. But it should be possible to use the same shaft for slightly different purposes. For example, it would be found that for an inch shaft for which the values of the range factor are 0·5 and − 0·5, when paired with a standard unilateral hole the fit limits will be between a clearance of 0·0015 inch and an obstruction of 0·0003. The shaft therefore is suitable for a push fit. In the bilateral hole the fit limits would lie between a clearance of 0·0009 and an obstruction of the same amount. The shaft is suitable for a keying fit.

It is to be hoped that in some such way as this agreement may be reached, and it may be possible in the near future to issue a standard chart of allowances and tolerances accepted by all so far as the shafts are concerned, and equally applicable to the unilateral and bilateral hole.

I would urge, in concluding this part of my subject, that looking forward we should have regard to the interests of the

many firms who do not now use limit gauging, but would do so if a standard system were generally recognized, rather than to the convenience of those who have adopted a system excellent in many respects but in my opinion not quite the best. I would add that, in speaking thus, I am expressing merely my private opinion. As Chairman of the Committee, it will be my endeavour to give effect to their decision when that decision is made.

Up to the present I have dealt mainly with running fits, to which it is generally agreed the $\sqrt{D}$ law applies; it remains to consider the transition and interference fits. The former include the key fits, and a light drive fit. These all are intended to be fairly close fits to the hole, and if the hole is to conform to the $\sqrt{D}$ law it is clearly necessary to adopt it for transition fits also.

The case of the interference fits is somewhat different; there are some reasons* for holding that for a force fit or a shrink fit an obstruction proportional to the diameter is the correct result to aim at, and upper limits given by $0{\cdot}0002 \times D$ or $0{\cdot}0004 \times D$ have been suggested. With these there is the difficulty that owing to the difference in the character of the curves if a law suitable for the larger diameters be adopted then, for the smaller diameters, the corresponding limits may actually be less than those assigned to a shaft intended to have a slacker fit.

It is possible that the solution may be to retain the $\sqrt{D}$ law for the smaller sizes, for which the heavier obstruction given by the D law is, perhaps, not required, changing to the D law at some convenient diameter.

Another solution would be to make the lower limit for the drive shaft equal to the upper limit for the hole, plus terms proportional to D, say $0{\cdot}0004D$, and thus obtain the necessary interference; beyond this, a tolerance of the same amount as for the hole would be permitted, Thus assuming the standard hole, the shaft limits would be $0{\cdot}0002 \times (1 + n) + 0{\cdot}0004D$ and

$$0{\cdot}0002\,(1 + n) + 0{\cdot}0004D + 0{\cdot}0002\,(1 + n).$$

* The main reason put briefly is that, assuming similarity of form, the stresses in the material will, if this law be followed, be independent of the dimensions.

It may also be found desirable to prescribe a second series of shafts for interference fits suitable for holes with larger tolerances than the normal, holes, for example, with a range factor of 4 instead of 2. However, force fits and shrink fits must depend greatly on the material employed, and it is difficult to lay down rules which shall be generally applicable.

I have dealt hitherto with plain shafts and holes; the same principles apply to the limit gauging of screws, and these have recently been dealt with in Reports Nos. CL 7270 and 7271, issued by the Standards Association. The need for the mass production of ammunition led during the war to a great development of this part of our subject. There is one point, however, to be noticed. The standardization has proceeded throughout on the shaft basis; the bolt is assumed to have correct dimensions with a negative tolerance; any allowance prescribed to permit of an easy fit is given on the nut. To be consistent with the standardization proposed for plain shafts and holes this should be reversed; the hole should be of nominal dimensions, which, on the unilateral system, should fix its minimum size, the tolerance being positive. Allowances for fit should be made on the shaft. This plan has been adopted by the American Commission in its recent report, and an alteration in our system will need the careful consideration of the Standards Committee. In practice the alteration would not lead to difficulties if it should prove, as was shown to be the case in America, that the large majority of bolts are already below size to an extent considerably in excess of any reasonable tolerance.

We come now to the gauges to be employed in the mass production of work to limits. For each element a "go gauge" and suitable "not-go gauges" are needed, and here let me emphasize one most important point to which attention has been frequently called by various writers, and by none more forcibly than by Mr. William Taylor, who has done so much to promote accurate thinking in connexion with our subject.

A go gauge must be a complete gauge, checking at once all the elements of the object gauged.

A not-go gauge can properly check only one dimension of

the object gauged. Thus, for satisfactory working, a number of not-go gauges is required, one to check each element of the part examined.

This is well illustrated by Mr. Taylor's model, Fig. 10, for testing a rectangular photographic plate. The gauges shown, two rectangular holes, one just larger than, the other just less than the plate, would also pass plates such as *b* and *c*, in addition to *a*, the rectangular plate they are intended to gauge.

Or, again, consider the ordinary ring gauges used to check a

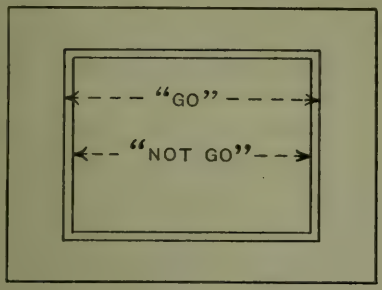
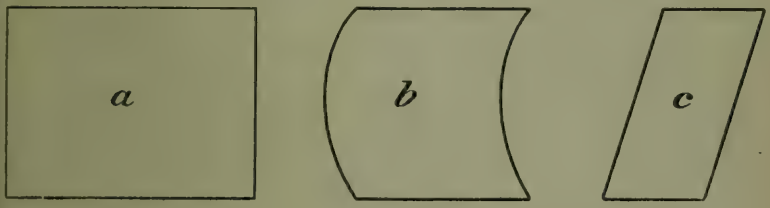


FIG. 10.
Taylor Gauges.



shaft of circular section; they will also pass a shaft of oval section, provided its maximum diameter lies between the maximum and minimum diameters permitted for the circular shaft for which the gauges are intended; the difficulty is met by the use of a gap gauge of proper size. This can be applied so as to test each diameter separately.

The need for a number of not-go gauges is more urgent when gauging an object of more complicated form such as a screw thread. The first requirement, of course, is that a screwed bolt should enter a nut of accurate size and form. To test this a ring screw-gauge

of accurate shape and dimensions is clearly necessary, the go gauge must be complete in all particulars. But a screw has many elements, and any or all of these may be in error. The full or the core diameter may be too small, the thread may be thin and the pitch incorrect, its error being compensated by the thinness of the thread; the angle may be wrong and the shape of the thread at crest and root incorrect, and yet the screw may reject the not-go gauge and thus be accepted. A single not-go gauge will not suffice to test these various elements; its use may even lead to the acceptance of incorrect work. Suppose, for instance, a not-go screw-threaded gauge is employed and the full diameter of the screw is correct, the other elements being wrong, in spite of this the screw will not enter the gauge and will be accepted.

In the early stages of the War screws for munition work were supposed to be tested by complete screwed go and not-go gauges, and the Woolwich list of gauges prescribed a pair of screwed gauges to test each threaded part. When asked to undertake, at the National Physical Laboratory the testing of these gauges for munitions, my first action was to call attention to the uselessness of the not-go screwed gauge and to recommend its abolition. In this, as indeed throughout, I had the cordial support of Sir Henry Fowler and of Mr. Ryan, and after a somewhat amusing series of minutes the recommendation was approved, thus halving the number of screwed gauges required. I have not attempted to calculate the saving of expense resulting from this; its effect on the output of munitions and the progress of the War can hardly be estimated.

In practice it is, of course, not possible to apply a not-go gauge to each element of a batch of bolts or nuts; the steps which can be taken to secure a uniform product will be considered later. Meanwhile it is sufficient to bear in mind the fundamental principle that a not-go gauge checks one element only.

Having established this we can pass on to consider the gauges necessary to secure that the work produced shall be within the prescribed limits and accepted by the purchaser.

The manufacturer wishes to ensure this; he will, therefore,

arrange that the gauges he employs to test his product shall pass nothing outside the limits; they will, if anything, reduce slightly the tolerance on the work; the high gauge will be somewhat less than the high limit for the work, the low gauge somewhat greater than the low limit; we may, perhaps, call these the manufacturers' gauges or the makers' inspection gauges. But he will also desire that all work coming from the shops to his inspection room should pass his own gauges, and therefore the gauges issued to the workman

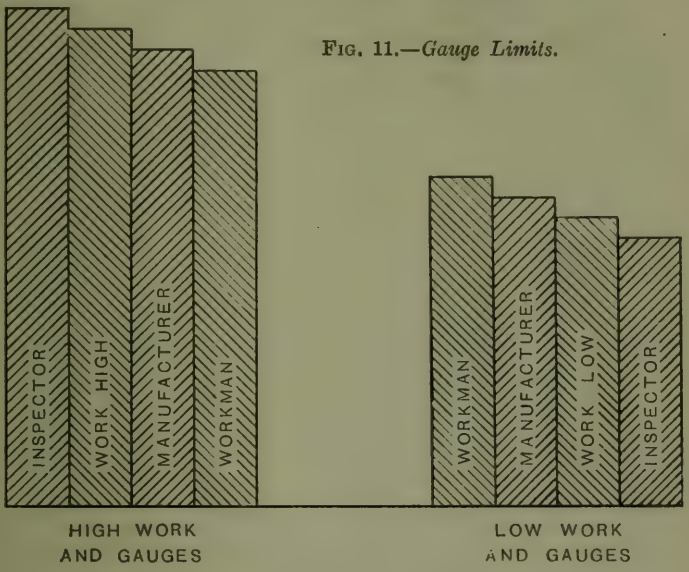


FIG. 11.—*Gauge Limits.*

will be such as to secure this. The workman's high gauge will be less than the manufacturer's, his low gauge will be greater; his gauge limits will reduce still further the tolerance on the work; the amount of this reduction will depend on the judgment of the manufacturer. Classing these two sets of gauges together as shop gauges, we see that in shop gauges the high gauge must be less than nominal size, the low gauge greater.

Turning now to the gauges used by the purchaser the reverse is the case. The purchaser's gauges—inspection gauges they are frequently called—must reject no work which is within the

prescribed dimensions. The high gauge must be not less than nominal. Any tolerance must be positive, the low gauge must be not greater than nominal; any tolerance must be negative. These arrangements are shown in Fig. 11. It will be noticed that the tolerance, the difference between the high and low limits, is least for the workshop gauges and increased up to the inspector's gauges.

In addition to the above, the gauge room will require a set of reference gauges in order to check the dimensions of those issued to the shop. Formerly these were usually a complete set of gauges approximately of the same pattern as those used in the shop or by the inspector with which the shop or manufacturer's gauges were compared. The introduction of the Johansson slips has to a great extent rendered these unnecessary. I may assume, I think, that these most valuable adjuncts to limit gauge work are known to my hearers. An account of great interest of the methods adopted by Messrs. Pratt and Whitney for their manufactures will be found in "Machinery" for April 1920, while reference should be made to the method devised by Messrs. Sears and Brookes at the National Physical Laboratory for the same purpose, and to Mr. Brookes' millionth measuring machine employed in testing the gauges, Fig. 12, Plate 16. Fuller details will be found in the Report of the National Physical Laboratory for 1919, published by H.M. Stationery Office.

In using the Johansson slips as reference gauges, a number are wrung together to give the required length; a plug gauge can be tested against these with the aid of a suitable micrometer or measuring machine, while a calliper gauge can be fitted to them directly. To test a ring gauge is more difficult. If of small size, a plug can be made to fit it, and then tested in the usual way in a measuring machine; if of large size, the method adopted at the National Physical Laboratory during the War and indicated in Fig. 13 is applicable. In this a gauge of known length is made up by wringing together a series of Johansson gauges and adding at each end a cylindrical gauge of known diameter; this compound gauge is then applied to test the diameter of the ring gauge.

For many purposes then a box of Johansson slips serves as a

complete set of reference gauges, and it is to be hoped that before long these may be obtainable in quantity from British sources.

For screwed work the problem is more difficult. It is clearly impossible to test completely bolts and nuts or other screwed parts made in quantity. The real solution of the problem will, I think, be found in the provision of satisfactorily accurate tools for the manufacture of the screws. Mr. William Taylor has recently increased the debt due to him from industry by undertaking on the part of his firm to supply suitable screwing tackle for certain classes of instrument work. The standardization of taps and dies and other appliances for cutting screws is urgently needed; if they are kept

FIG. 13.
Testing Ring Gauge.

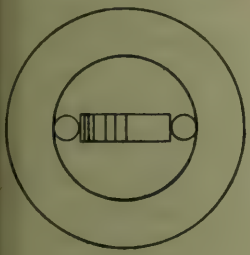
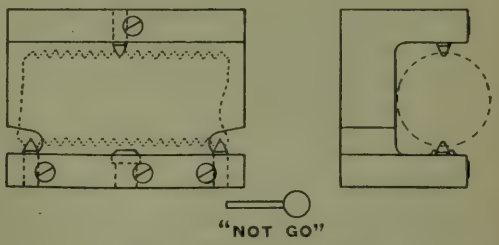


FIG. 14.
Taylor Screw Gauge.



within certain definite limits, the occasional inspection and testing of the product as it comes from the machines will be sufficient to assure the manufacturer that his goods are within the tolerances allowed. For such inspection optical projection combined with the use of a go gauge to check the over-all dimensions, and to secure concentricity of the parts, is probably the most satisfactory method. Various forms of optical projectors for screw work were devised at the National Physical Laboratory during the War. For an account of these, reference should be made to the National Physical Laboratory Report,* 1919. They were designed to be of high accuracy and check screw gauges, not merely screwed work; while

* Extracts from this Report will be found in Appendix VI (page 1119)

in Appendix III will be found a description of an instrument designed originally by Mr. R. P. Wilson and now manufactured by Messrs. Hilger for comparing a screwed bolt with a standard gauge.

To test a ring is more difficult. A screwed plug gauge forms the necessary go gauge. The other dimensions may be tested by taking a cast (National Physical Laboratory Report, 1919, page 75) and examining this optically, or by the use of not-go gauges, such as those designed by Mr. W. Taylor (Appendix IV). One of these is shown in Fig. 14.

Another method of testing small bolts such as those used for aeroplane parts or engines was introduced during the War by Major Bishop, of the Aeronautical Inspection Department. An account of this, taken from the E.S.C. Report, No. 84 on British Standard Fine Screws is given in Appendix V.

Let A and B, Fig. 29 (page 1116), represent the profiles of the largest and smallest bolt which can be accepted, each profile being of correct form. The space between these two defines the tolerance permitted, and any screw such as C of which the profile falls between A and B can be accepted, and will enter the nut without undue slackness of fit. By the use of suitable projection apparatus, an image of the screw under test can be formed on a screen on which the two standard profiles have been drawn, and its suitability thus determined. This is the basis of Major Bishop's method.

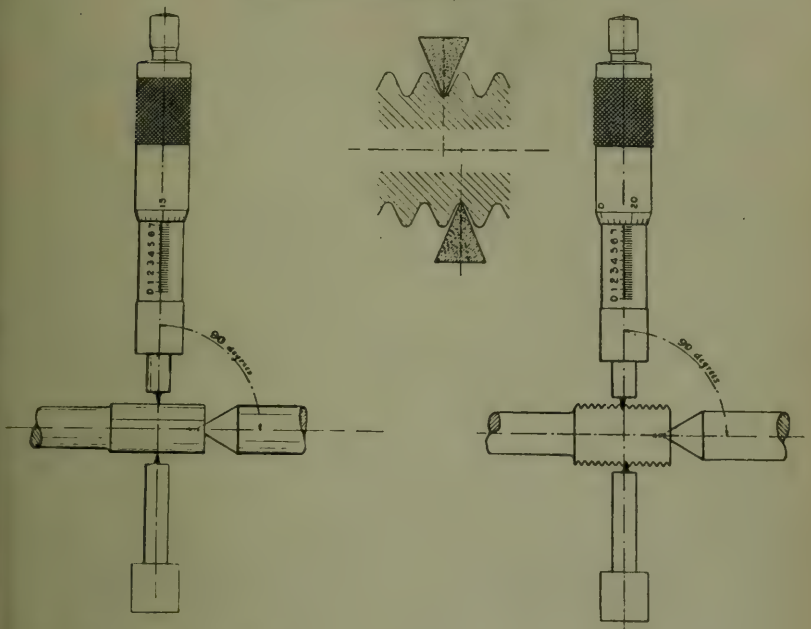
To go fully into the methods suitable for the testing of screw gauges would occupy another lecture. Most of these were developed at the National Physical Laboratory during the War, and a very interesting account of the work is given in the Laboratory Report for 1919. Fuller references will be found in Appendix VI, extracted from this Report, and it may be useful to give illustrations of the various forms of apparatus designed for the purpose. A Chart * showing the number of gauges tested between January 1916 and September 1919, was shown on the screen. Up to the date of the Armistice, 11th November 1918, 1,083,862 gauges were tested officially and some 33,000 unofficially for private firms. Between

* *See* N.P.L. Report 1919, Fig. 4.

November 1918 and September 1919 115,826 official and about 10,000 unofficial gauges have been handled.

Fig. 15, Plate 16, shows the floating micrometer screw diameter measuring machine, originally constructed at the Laboratory, and since manufactured in large numbers by Messrs. Taylor and Hobson, in whose works the design was completed with the assistance of

FIG. 16.—*Floating Micrometer.*



Mr. Turner, of the Metrology Department, while Fig. 16 indicates more clearly the method of its action.

Figs. 17 and 18, Plate 17, give two patterns of pitch measuring apparatus. They are now manufactured by Messrs. G. Cussons, of Manchester, and are generally well known, while Fig. 19 (page 1106) gives a curve of errors tabulated by the aid of such an instrument.

Horizontal and vertical projection apparatus is shown in Fig. 20, Plate 17; Fig. 21, Plate 18; Fig. 22 (page 1107); and Fig. 23, Plate 18. Fig. 24, Plate 18, is a reproduction of the diagram

FIG. 19.—*Pitch Error.*

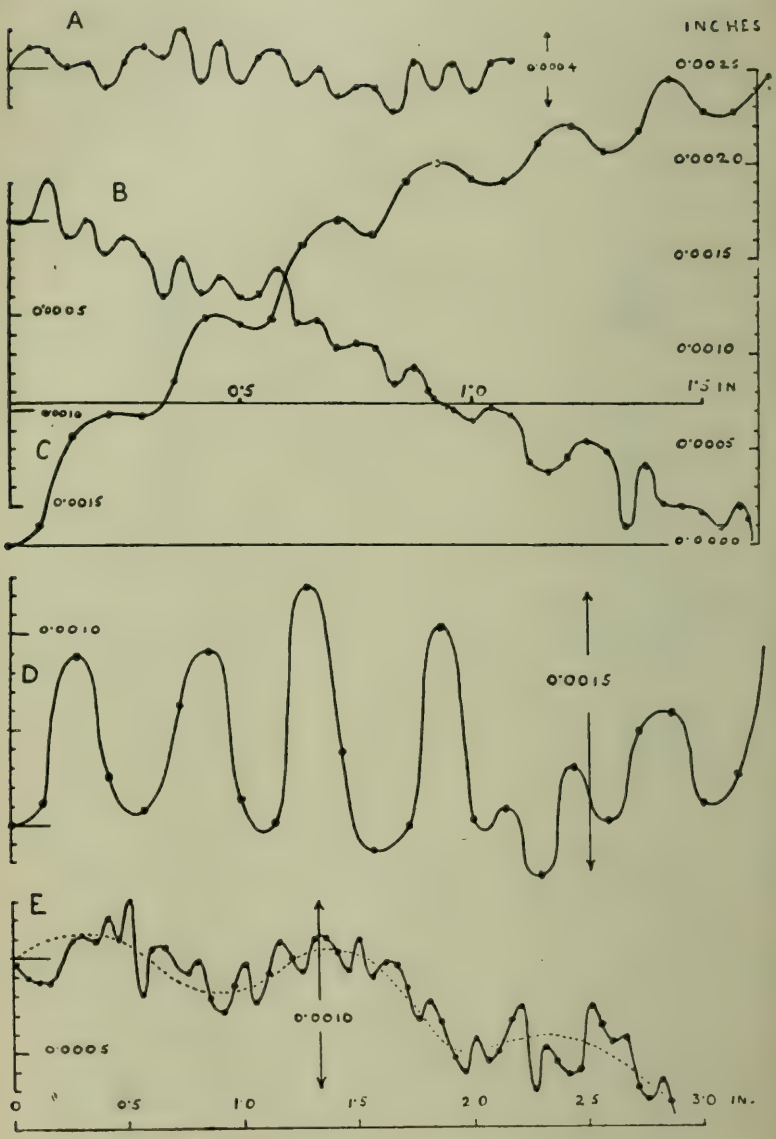
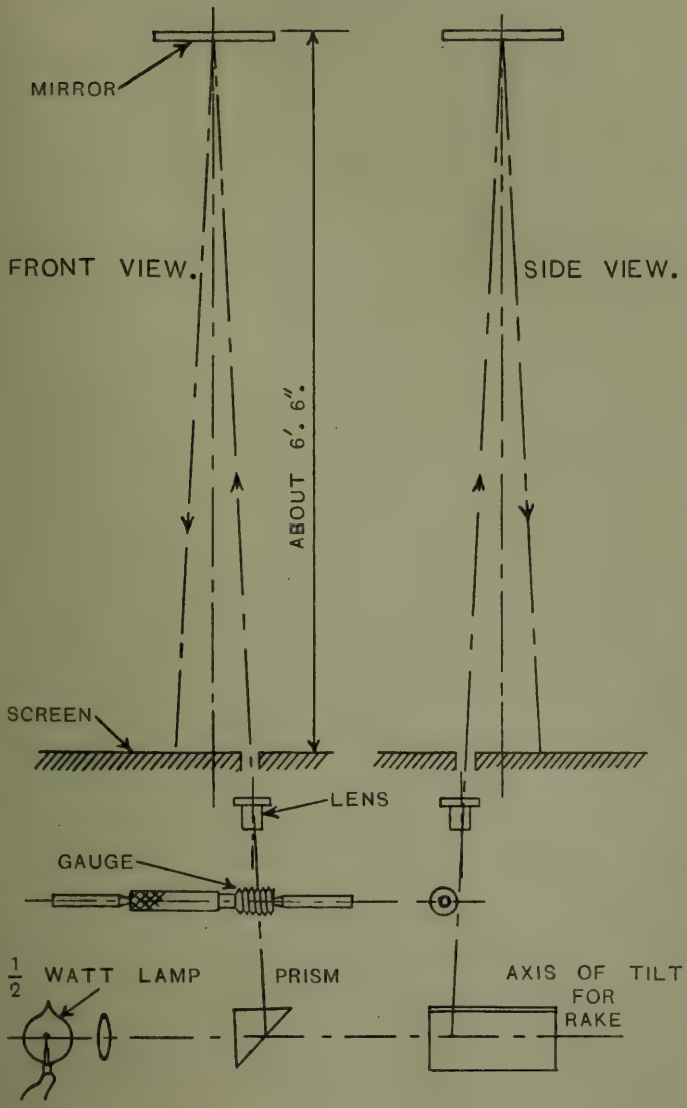


FIG. 22.—*Vertical Projector.*



used with the vertical projection apparatus. Descriptions of these various appliances will be found in the Laboratory Report for 1919 already referred to, or in a pamphlet, "Notes on Screw Gauges," compiled by the Laboratory Staff, and now published by H.M. Stationery Office.

One further important aspect of the work must be mentioned. International standardization is a wide question, but it is coming to the fore in many directions. The limits suitable for various classes of work are fairly definite, and do not depend on the nationality of the manufacturer; it would seem desirable that as far as possible all nations should adopt the same limits for such articles as screws and nuts, for the parts of motor cars and for other machinery which has a wide area of distribution. To one who realizes the advantages which have accrued to pure science by the general adoption of the C.G.S. system of units, the idea of an international system of limits and limit gauging appeals strongly. And at present the matter is being considered in many parts of the world.

I have not sufficient information to say how far there is unanimity of opinion with regard to plain cylindrical work in America, but limit gauging is very widely used there. On the Continent, in Germany, Belgium and Switzerland, the matter is receiving the fullest attention. No doubt the difference between our system of units and the metric system will introduce difficulties, but the use of 0·0004 inch or 0·01 millimetre as a unit enables the tables of limits to be readily transcribed from inch to metric measure. As to screws in America, very valuable work has been done by the Commission under the chairmanship of Dr. Stratton, of the Bureau of Standards, which has recently issued a preliminary Report giving a complete series of limits for screws in use in the United States.

The United States thread, as is well known, has an angle of 60° with a top theoretically flat, but experiment has shown that for many purposes the screws are interchangeable with our Whitworth thread, provided the pitches are the same, and it is satisfactory to note that with one exception the pitches of the American series agree with our British Standard Whitworth system. The one

exception is the half-inch, for which a pitch of 13 threads is now standard in America in place of the original 12 threads of the Whitworth system, and, I believe, of the original Sellers system. I trust it may not be too late to ask our American colleagues to reconsider this point, and thus secure uniformity.

With the fine threads the case is, I regret to say, different. The American Commission has adopted as standard the series standardized by the Society of Automotive Engineers, which are in all cases from 2 to 4 turns per inch finer than our British Standard Fine Series. It may be that both series are required, but this hardly seems probable, and steps will, I trust, shortly be taken to discover the wishes of English manufacturers before they are irretrievably wedded to either series, and to standardize a set of pitches generally acceptable, and which we may hope to see adopted internationally.

In conclusion, let me express to the Council my keen sense of the honour they have conferred upon me recently by electing me as an Honorary Life Member of the Institution, and inviting me to deliver this Lecture. The task has not been easy. I am fully conscious of many shortcomings in its performance, but I trust what I have said may be of service in promoting an object I have for long had very much at heart, and in advancing both the science and the practice of the mechanical engineer.

The Lecture is illustrated by Plates 16 to 20, and 16 Figs. in the letterpress, and is accompanied by 6 Appendixes with 3 Figs.

Plates 16, 17, and 18, are reproduced from the National Physical Laboratory Report for 1919, by kind permission of the Controller of H.M. Stationery Office.

The attendance was 75 Members and 37 Visitors.

The LECTURE was repeated by Sir RICHARD GLAZEBROOK in Manchester, Birmingham, and Glasgow:—

MANCHESTER, in the Engineers' Club, on Thursday, 18th November. Mr CHARLES DAY, *Member*, was in the Chair, and about 100 were present.

BIRMINGHAM, in the Medical Lecture Theatre of the University, Edmund Street, on Thursday, 25th November. Sir GERARD A. MUNTZ, Bart., *Member of Council*, presided, and about 40 were present.

GLASGOW, in the Royal Technical College, on Monday, 6th December. The Right Hon. Lord WEIR, P.C., D.Sc., *Vice-President*, presided, and 100 were present.

APPENDIX I.

Mr. Hedley J. Thomson's Step System.

Consider the series of ranges given by the expression

$$x \qquad x+y \qquad x+2y \qquad x+(n-1)\,y$$

x and y being any two lengths, and let D_n be the diameter at the end of the nth range. D_{n-1} at the commencement of the same, the end that is of the $(n-1)$th range.

D_n is the sum of n terms of the above progression. D_{n-1} the sum of $(n-1)$ terms.

Thus

$$D_n = \frac{n}{2}\left\{2x + (n-1)\,y\right\}$$

$$D_{n-1} = \frac{(n-1)}{2}\left\{2x + (n-2)\,y\right\}$$

And if D be the diameter corresponding to the middle of the nth range

$$D = \tfrac{1}{2}\left\{D_{n-1} + D_n\right\}$$

$$= \tfrac{1}{2}\left\{x\,(2n-1 + y\,(n-1)^2\right\}$$

$$= \tfrac{1}{2}\left\{yn^2 + (x-y)\,(2n-1)\right\}.$$

Hence, if $x = y$, we have

$$D = \tfrac{1}{2}\,yn^2 = n^2\,\frac{x}{2}.$$

Thus

$$n = \sqrt{\frac{2D}{x}} \text{ or } \sqrt{D} = n\,\sqrt{\frac{x}{2}}.$$

Hence, an allowance of the form $a + b\sqrt{D}$ may be written

$$a + b\,\sqrt{\left(\frac{x}{2}\right)}\,n,$$

or putting

$$a = b\,\sqrt{\left(\frac{x}{2}\right)}$$

we get

$$\text{Allowance} = b\,\sqrt{\left(\frac{x}{2}\right)}\,(1+n).$$

Thus, as we step from range to range, for example, from n to $n+1$, the allowances or tolerances increase by equal steps of $b\sqrt{\frac{x}{2}}$. Hence, if the ranges form the series

$$x, 2x, 3x \ldots\ldots nx,$$

the limits increase at the end of each range by the constant quantity $b\sqrt{\frac{x}{2}}$ where b is any constant.

This will be true, even if we do not put $a = b\sqrt{\frac{x}{2}}$, but write k for the ratio of a to $b\sqrt{\frac{x}{2}}$ so that $a = k \cdot b\sqrt{\frac{x}{2}}$. We should then find

$$\text{Allowance} = b\sqrt{\frac{x}{2}}\{k+n\};$$

it is found, however, that suitable values are given by making $k = 1$, and the expression is thus simplified.

Restricting ourselves now to the case in which $x = \frac{1}{10}$ of an inch and $k = 1$, and writing for $\frac{b}{\sqrt{20}}$ the quantity $0{\cdot}0001 \times r$, where r is some suitable constant, we have as a value for the limits the expression $0{\cdot}0001'' \times r\,(1+n)$, and for the increase at each step $0{\cdot}0001'' \times r$.

Moreover, if $x = \frac{1}{10}$, $D_n = \frac{n}{20}(n+1)$, $D_{n-1} = \frac{(n-1)}{20}n$, and D the mean diameter of the nth range lies between $\frac{1}{20}(n-1)\,n$ and $\frac{1}{20}\,n\,(n+1)$.

APPENDIX II.

Mr. Hedley J. Thomson's Apparatus to Illustrate Fits.

This apparatus is intended to give a practical idea of the amounts of play which are likely to occur between nominal shafts and holes when made to various tolerances. The length of engagement is twice the diameter.

The apparatus for a shaft $\frac{3}{4}$ inch in diameter consists of a steel spindle, the central portion of which is tapered from 0·75 to 0·765 over a length of $1\frac{1}{2}$ inches, the taper being 1 in 100. A ring $2\frac{3}{4}$ inches in length is bored and ground to the same taper (the diameter at the smaller end being 0·75 inch) and fits over the spindle. The latter is supported horizontally on a suitable frame, and is fitted with an adjustable sleeve at each end for limiting the travel of the tapered ring along the tapered portion of the spindle. The sleeves have graduations which register against a line on the spindle, the

divisions being marked with the different tolerances for the shaft. If one of the sleeves is set so as to indicate a certain tolerance, and the ring is slid along the spindle until it makes contact with the sleeve, then the play between the ring and spindle in that position gives either the maximum or the minimum which can occur with that particular type of fit. One sleeve is intended to give the relative position of the ring and spindle for the maximum play, and the other for the minimum play. Owing to the extra length of the ring over that of the tapered part of the spindle, a length of engagement of $1\frac{1}{2}$ inches, or twice the diameter of the shaft, is always ensured at every position of the sleeves.

Similar apparatus has been constructed for shafts $1\frac{1}{2}$ and 3 inches.

Tests by the N.P.L. show that the apparatus will give indications of the true play within some few ten thousandths of an inch.

APPENDIX III.

The Wilson Projection Comparator.

The apparatus consists of a collimating lens B which forms a parallel beam of the rays diverging from a source A, Fig. 25. The screw C under test is placed in this beam, its axis being at right angles to the beam. D is an achromatic projection lens divided as shown into two equal portions. The parts are separable by means of micrometer screws. The lenses are adjusted by these screws until their distance apart is equal to the effective diameter of the screw C under test. Each half lens then would form on the screen F an image of one side of this screw, and these two images would be

FIG. 25.—*Diagram illustrating in plan the optical system.*

at some distance apart. Two achromatic prisms E are placed between the lenses and the screw in such a manner as to bring the two images together on the screen as shown in the figure. If the screw be accurate in form the crests on one side intermesh exactly with the roots on the other. If, when the apparatus is adjusted, this is not the case, the defects of the thread are made visible.

The apparatus is adjusted by placing an accurate screw gauge in position, the lenses having been already set to the proper distance apart, and adjusting the prisms so that the projected images neither overlap nor fail to touch.

If there is an overlap the diameter of the screw under test is too large, if there is a gap it is too small. Defects in the shape are readily detected.

Fig. 26, Plate 19, shows the complete apparatus with a gauge in position.

Fig. 27. Gives a view of the projection apparatus, while in Fig. 28, Plate 19, we have a series of typical screw thread projections from which we infer—

A. Effective diameter correct.

B. Effective diameter correct; the heaviness of the flank outlines is due to the rake of the thread.

C. Diameter too small.

D. Thread conical and too small.

E. Diameter too big.

F. Thread conical, too small at one end, too large at the other.

Fig. 28 B illustrates a common difficulty in connexion with screw thread projection. The light is travelling at right angles to the axis of the screw; but the thread is inclined to this direction by an amount measured by the angle of the helix of which the thread forms part. Some of the light therefore is cut off, and to get a true projection of an axial section of the thread the direction of the light ought to be parallel to that of the thread. When one side only of the thread is projected this is secured by tilting the light slightly, but the tilt required on the two sides of the thread is opposite, and to secure this in Mr. Wilson's apparatus a special fitting is necessary.

This can be added to the apparatus, but for many purposes for which it is employed, for example, the testing of numbers of identical screws—not accurate gauges—the error introduced by its omission which causes the thickening of the thread in B is too small to be of importance.

The apparatus was designed by Mr. R. P. Wilson, and its introduction during the latter stages of the War enormously increased the facilities for testing screws such as the 2-inch screw on the fuze.

I am indebted to Messrs. Hilger for the illustrations of the apparatus.

APPENDIX IV.

Mr. Wm. Taylor's Gauges.

The set of gauges designed by Mr. Taylor, and which he generously placed at the disposal of the Standards Committee are illustrated in Fig. 14 (page 1103). See also E.S.C. Report No. 38.

They consist of the following:—

I. GAUGES FOR A BOLT.

(1) A three-point gauge. In this gauge three points are placed as shown in Fig. 14, two on one side of a slot in a block of steel, and the third on the opposite side midway between them, in such a manner that a screw of correct effective diameter and pitch will just pass between them. The points are so adjusted that they bear on the slopes of a correct thread midway between the crest and the root of the thread.

A thread of incorrect pitch will pass the gauge—a go gauge—provided its effective diameter has been sufficiently reduced. To check too great reduction of effective diameter there is a small flat on the inner surface of the block opposite to the central point, and a small cylindrical pin is provided. If the effective diameter of a screw under test is within the assigned limits, it is not possible to insert the pin between the flat and the slopes of the thread. The gauge forms a not-go gauge for effective diameter; if the pin can be inserted the diameter is too small.

(2) Two ring gauges, go and not-go, for checking the full diameter.

(3) Two gap gauges ground thin at the edges—go and not-go—for checking the core diameter.

The three go gauges may suitably be replaced by a complete ring gauge of accurate form and dimensions. In this case the three-point gauge is used only as a not-go gauge to control pitch and effective diameter.

II. GAUGES FOR A NUT.

(1) A complete plug gauge of accurate form and dimensions as a go gauge.

(2) A not-go gauge for the core diameter. A plain plug of suitable diameter.

(3) A not-go gauge for effective diameter. A screw gauge with a single turn of thread, the crest ground off and the root is ground deep, so as to bear only on the middle of the slopes, the dimensions are such as just not to enter a nut of the largest admissible effective diameter.

(4) A not-go gauge for full diameter. A screw gauge with a single turn ground very thin so as to bear only at its crest, that is, on the full diameter of the nut, and of such dimension as just not to enter a nut of the largest admissible full diameter.

APPENDIX V.

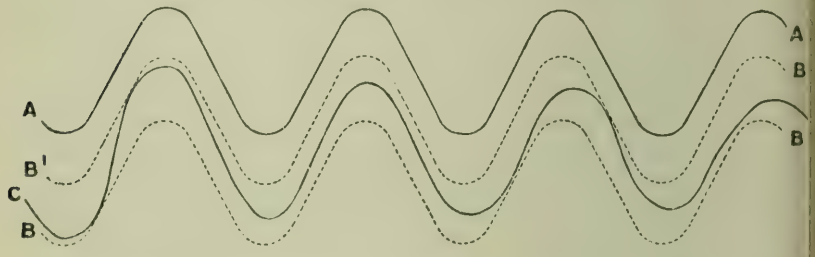
Captain Bishop's Method, Grade and Play.

E.S.C. Report, No. 84, 1918.

Let A, Fig. 29, represent the profile of a standard bolt; it will just enter a standard nut, so that A may also represent the profile of that nut.

Any bolt whose profile lies inside that of A will be interchangeable with A; it will enter the nut. Let C be the outline of such a bolt, having errors

FIG. 29.—*Projection of Thread, Bishop's Method.*



C C = Actual Thread Form of a Screw of long Pitch and tapering in diameter.
A A = Correct Whitworth Thread.
B'B' = " " "
B B = " " "

(Reduced from B.E.S.A. Report, No. 84—1918. Pl. 1.)

of pitch, angle, and diameter, and let B be the largest bolt of accurate form which would enter C if C were a nut.

Then twice the distance between A and B, that is, twice the maximum distance between A and C, is defined as the "grade" of C.

In the figure as drawn there is a space everywhere between A and C; C would be a loose fit in the nut A. Let B^1 be the least nut of accurate form which C will enter. Then the distance between A and B^1, that is, the minimum distance between A and C, measures the shake. Twice this distance is known as the "play." If the grade is small the maximum errors are limited; if the play is small the fit is improved; we can use these quantities to determine the quality of a thread.

To do this we must connect the breadth of the zones of grade and play with the errors of the thread.

Now it is known that the errors of pitch and angle of a bolt can be expressed in terms of the increase of effective diameter required to permit a nut of correct dimensions to pair with that bolt. Let the diametral changes required to compensate the angle and pitch errors respectively be y and z, and let x be the measured error of effective diameter of the bolt each measured in thousandths of an inch. Then the distance between the two profiles A and B is equal to $\frac{1}{2}(x + y + z)$. For if C were of correct form, but too small by an amount x, it would coincide with B, and the distance between A and B would be $\frac{1}{2}x$. This distance is increased by $\frac{1}{2}y$ and $\frac{1}{2}z$ to compensate for angle and pitch errors.

Hence: Grade = twice distance between A and B $= x + y + z$.

Again, the distance between A and B^1 is $\frac{1}{2}(x - y - z)$.

For if C were of perfect form, but too small by an amount x, then B would coincide with C, and the distance between A and C would be $\frac{1}{2}x$. This is decreased by $\frac{1}{2}(y + z)$ to compensate for errors of angle and pitch.

Hence: Play = twice distance between A and B^1 $= \frac{1}{2}(x - y - z)$.

We can determine then the grade and the play if we can measure the errors in effective diameter, pitch, and angle, and from the latter determine the quantities y and z.

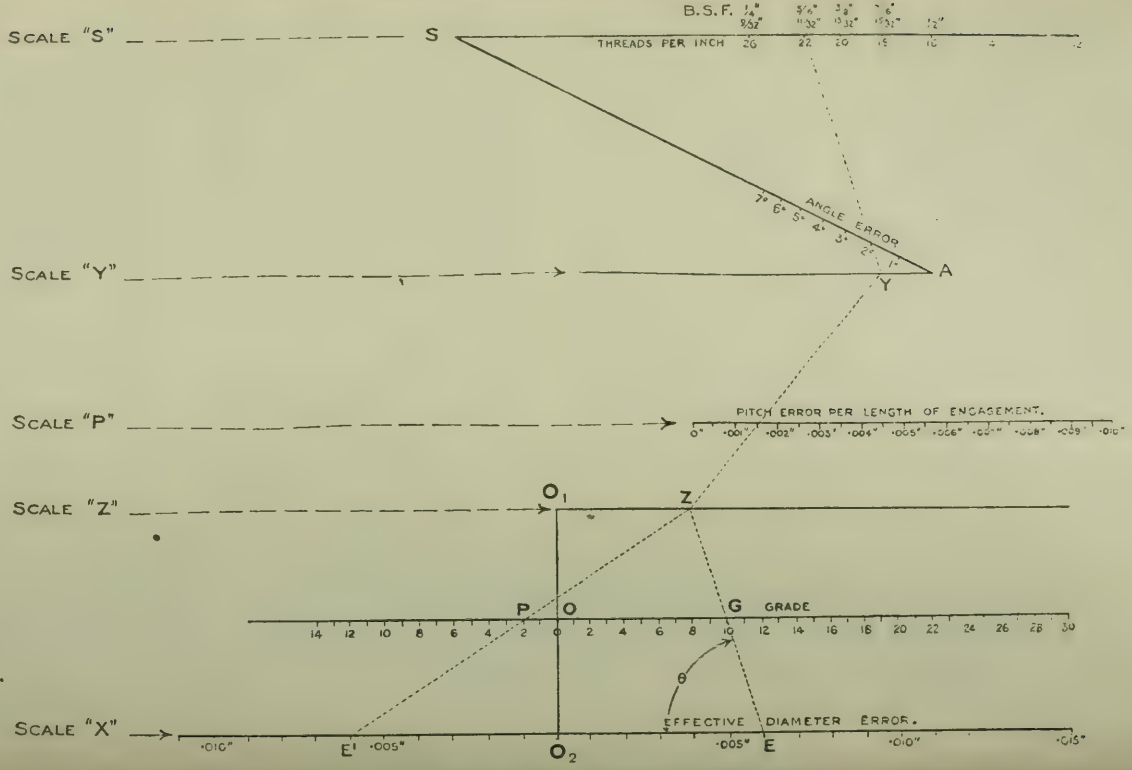
The play and grade can, however, be determined by a graphical construction due to Major Bishop.

In Fig. 30 (page 1118), S is a scale of threads per inch drawn to some convenient dimensions; SA, a line of convenient length drawn at any angle to SA; AY parallel to S is a scale giving the effective diameter error y corresponding to a given error of angle; the errors in angle are set off from A along the line AS. (The method of constructing these scales AS and Y is explained in the Report.) Scale P, also horizontal, gives the pitch error per length of engagement, and scale Z, also horizontal and at the proper distance below P, gives the total diametral error $y + z$ due to angle and pitch. Scale X below Z gives the effective diameter error; it is produced on both sides of the origin, and its divisions are the same size as those of Z. Midway between Z and X is a scale P, with graduations half the size of X and Z, and this scale gives the grade to the right of the origin –the play to the left.

To use the diagram. Join the number of threads of the given screw (22 in the figure) to the observed angle error (2° in the figure) and produce it to meet Scale Y in Y. Then AY is y, the error in effective diameter due to given angle error. Join Y to the observed pitch error measured per length of engagement (0·0015 inches in the figure), and produce the line to meet Scale Z in Z. The distance of Z from the origin O of this scale measures $y + z$.

Set off on the X scale the two lengths O_2E, O_2E^1, representing in each

FIG. 30.—*Grade and Play Chart for British Standard Fine Screws.*



(Reduced from B.E.S.A. Report, No. 84—1918. Pl. 1.)

case x, the measured error in effective diameter. Join ZE and ZE^1, cutting the P scale in G and P respectively. Then, remembering that the divisions of the scale P are half those of X and Z, we see the

$$OG = x + y + z = \text{Grade},$$
$$OP = x - (y + z) = \text{Play}.$$

If we arrange to specify the permissible errors of a screw in terms of the Grade and the Play the diagram gives us a ready means of determining these quantities and deciding if the screw is within the assigned limits.

APPENDIX VI.

Description of Gauge-Testing Apparatus designed and used at the N.P.L. 1915–1919. *Taken from the Laboratory Report for* 1919.

(Extracts from N.P.L. Report 1919, pp. 75–78, 80, 81.)

When testing a number of gauges during the earlier stages of the War, the importance of speeding up the mechanical tests was soon apparent, and the idea of the floating micrometer screw diameter measuring machine, supporting the gauge on fixed centres during measurement, and using two wires instead of three, was due to Mr. E. M. Eden. The first machine on these lines was made at the Laboratory, an old milling machine table serving as the base. Arrangements were then made with Mr. W. Taylor, of Messrs. Taylor, Taylor and Hobson, Ltd., to take up the manufacture of a number of machines on these lines, and Mr. Turner went from the Metrology Department to Leicester to complete the design in conjunction with Mr. Taylor. In this way there originated the standard type of 2-inch screw diameter measuring machine now so widely used, and frequently known as the Taylor machine. The operation of the machine is so simple and certain, that untrained observers of reasonable intelligence can be taught to use it, and after a week to a fortnight's practice are able to get consistent and correct readings, agreeing with those of any other observer to within 0·0001 inch. One observer can measure the effective or core diameter of about 100 plug screw gauges in a day, using one of these machines. The machine is illustrated in Fig. 15, Plate 16, and has been fully described in the pamphlet, "Notes on Screw Gauges," prepared by the Staff of the N.P.L. for the assistance of screw gauge makers and others, originally published by Mr. W. F. Parrott, and now obtainable from H.M. Stationery Office, price 2*s.* 6*d.*

About the same time Mr. Eden was engaged on the design of a new type of pitch measuring machine intended to simplify the process of pitch

measurement on gauges, and to relieve the complicated and comparatively slow working Whitworth machine of this work, thus setting it free for its more legitimate work of testing long screws. A great many such screws (trial screws cut on lathes of different kinds) were being examined with a view to advising intending gauge makers as to which, if any, of the lathes in their possession had lead screws of sufficient accuracy for use in such connexion. The results revealed a lamentable average of inaccuracy, but the work done was very valuable in helping gauge makers to make the best use of such tools as they had, and in saving fruitless effort. Later on special precision tools for screw gauge making began to be available and the testing of trial screws of this kind practically ceased. On the other hand, trial screws from the precision tools were submitted by their makers for certification before the machines were sold to intending customers.

Two or three examples of the first design of simplified pitch machine were made by the Automatic Telephone Manufacturing Company, of Liverpool, who took much interest in the work, but these, while they have been of some utility, were not perfect, and already Mr. Eden's ingenuity had devised another mechanism, which was incorporated in a new type of instrument, the now familiar 3 × 7-inch pitch measuring machine. The first machine of this kind was made in the gauge workshop and had an optical indicating mechanism. Later on the more elaborate 6 × 9-inch machine was designed on the same principle, but with a mechanical indicator, and finally the 3 × 7-inch machine was re-designed with a somewhat different type of mechanical indicator, taking advantage of the experience already gained. Both these types, the 6 × 9-inch and the 3 × 7-inch machines, have now become standardized, and have been manufactured for the Ministry, first by the L.C.C. Education Department (Paddington Technical Institute), and subsequently by Messrs. G. Cussons, Ltd., of Manchester, who continue to supply them to private customers. They also are described in the "Notes on Screw Gauges," and are illustrated in Figs. 17 and 18, Plate 17, of this Report.

The question of gauge projection was also taken up keenly by Mr. Eden, who developed first the horizontal and then the vertical type of projector, as now used.

The first screw gauge projector (other than a simple camera) was built on an old lathe bed, at one end of which was the arc lamp and condenser, while at the other the gauge was supported in front of the objective of a microscope, arranged with its axis horizontal. In front of the eye-piece of the microscope a 45° prism deflected the rays downwards so that an image of the screw-thread was formed on a horizontal disc at the extreme end of the lathe bed, in front of which the observer was placed. Great difficulty was experienced in finding suitable lenses to make this optical system work, and distortion was never completely eliminated. The apparatus, however, proved very useful at

the time it was first made, and remained in constant service from January 1916, until worn out and replaced by improved types. Only one machine of this kind was ever made.

The object in view in developing the "horizontal" projector was not so much the examination of screw gauges, as of complicated profile gauges of comparatively large size, and by persistent trials, coupled no doubt with some good fortune, Mr. Eden at length found an optical combination which was capable of projecting the image of such a profile to a magnification of fifty times, without measurable distortion of a field of about $1\frac{3}{4}$ inches diameter—a consummation which had earlier been pronounced impossible by optical experts. After trying many lenses by themselves without success, the effect of introducing a field lens between the gauge and the projection lens was tried. With certain particular pairs of lenses it was found that the distortion varied as the distance between the two lenses was changed. Moreover, the variation was such that by projecting a plain parallel plug gauge, either a barrel-shaped image or one narrower at the centre could be obtained. It then became clear that, by suitably adjusting the distance between the lenses, the distortion could be eliminated and a true parallel image obtained. This was done with a particular pair of lenses comprising a Ross 6-inch "Xpres" camera lens F 4·5 and a binocular objective lens from the same maker. These lenses were afterwards fixed in a mount at the correct distance apart, and the resulting compound lens produced an undistorted image, the definition of which was reasonably good over a 7-foot field at a magnification of fifty.

The combination of lenses described above was arrived at in February 1916, and a simple horizontal projection machine was designed, made, and put in use by March of that year.

Other types of compound lenses to cover a large field, and suitable for the horizontal machine, have since been found. Among them are the following:—

Ross Homocentric F 5·6 with field lens.
" " F 6·3 " "
Ross Tessar " "
Dallmeyer Serrac " "

A standard type of horizontal projector was designed in September 1916 and has since been manufactured in quantity by G. Cussons, of Manchester. It is shown in Fig. 20, Plate 17, and Fig. 21, Plate 18. Nearly 100 of these machines are now in use in England. They have also been exported to Canada, Australia, U.S.A., France, Switzerland, and Japan.

The horizontal projector, though not primarily intended for screw gauge work, has proved very useful in this connexion, and, since the more recently

evolved vertical projector has only lately become available in any quantity, has been generally used outside the Laboratory for this purpose.

The utility of the horizontal projector for the examination of screw gauges led Mr. Eden to try other designs intended to bring the object and the projected image more under the control of one observer. This appeared possible since a much smaller field is sufficient for screw gauge work than was aimed at for profile gauges.

In January 1917, the use of Kinematograph lenses for projecting screw threads was brought to the notice of the Laboratory. Investigations were made and several types of these lenses (Nos. 1, 4, 6 and 7), made by Dallmeyer, were found to be serviceable when properly corrected. This can be done by suitably adjusting the distance between the component lenses.

During the autumn of 1916, the idea of reflecting the image back to the neighbourhood of the lens had been thought of. The advantage of such a scheme is apparent, as only one observer is required. The projection apparatus can be manipulated and the resultant image seen by the same observer. To put the idea into practice a mirror was fixed half-way between the lens and the screen of a horizontal projector and the reflected image received on an auxiliary screen placed by the side of the lens.

In January 1917, an apparatus was made in wood to try this scheme with the light travelling vertically instead of horizontally. The result was quite satisfactory, and this apparatus was used from January 1917, until about a year afterwards, when it was replaced by later designs.

In this arrangement the axis of the gauge, and the surfaces of the screen and of the mirror above are accurately horizontal. The axis of the lens is truly vertical. The rake of the light is adjusted by slightly tilting the prism, as seen in the front view, about an axis perpendicular to the paper. The body of the experimental machine took the form of a shallow box with a hinged lid, which formed the screen and provided a mount for the No. 4 Dallmeyer Kinematograph lens. The gauge holder and prism, with the rake adjusting gear, was attached to the under side of the bottom of the box. The light came in horizontally from the side, on a level with the prism from a half-watt lamp and condenser. To insert the gauge the lid was raised. The gauge-holder was provided with a micrometer screw operating in the diametral direction, which enabled measurements of the diameters or depths of threads to be made if required.

As stated earlier, the projected image of the screw-thread was arranged to be at a magnification of exactly fifty diameters. To determine errors in the form of the thread the image was then compared with a diagram showing the standard form of the thread drawn out to the same magnification. The earlier diagrams drawn in January 1916, were simply line drawings made on Bristol board backed with three-ply wood and varnished. Such diagrams had

to be drawn to an accuracy of about 0·005 inch, which represents 0·0001 inch at a magnification of fifty. These diagrams were produced for all the various pitches of Whitworth, Metric and B.A. screw-threads.

When the standard horizontal projectors were being supplied to outside firms manufacturing screw gauges, the supply of thread form diagrams also had to be considered, and it became essential to devise some simple way of printing or reproducing them to the required accuracy. Photographic methods were tried; a few correct negatives were obtained, and from these any number of positives on glass could have been produced.

At this point, however, the Bentley Engineering Company, who were using a projection apparatus, produced, with the assistance of a firm of printers, thread form diagrams printed on zinc. This method involved drawing out a master diagram on zinc plate, and from this any number of accurate reproductions could be produced. This solved the difficulty of producing thread form diagrams. The Laboratory undertook to draw out the master diagrams and the production of the prints was left to the firm mentioned above.

The radial arm being raised above the back plate throws a shadow on to it and the arm is adjusted so as to bring one of the edges of the shadow parallel to the corresponding flank of the image of the thread. With the use of this instrument on either the horizontal or vertical projection apparatus the angles of the flanks of the image of the thread can be quickly and accurately determined.

Having proved from the experimental machine that the vertical projector scheme was satisfactory, a design was put in hand for one to be built in metal. Two of these machines were made in the Gauge Workshop, the first being put in use in June 1917. This design has no adjustment for moving the gauge in the direction of its axis, except by sliding the gauge holder along its vees. In the diametral direction a micrometer screw adjustment is provided, but this was intended as a fine adjustment only and not for measuring purposes. The machine would take screws up to 2 inches in diameter and was fitted with a No. 4 Dallmeyer Kinematograph lens. The machine was intended only for *inspecting* the form of thread using standard diagrams.

A more elaborate machine, since known as the Standard Vertical Projector, was designed in November 1917, and is shown in Fig. 22 (page 1107) and Fig. 23, Plate 18. This machine was provided with micrometer screws for traversing the gauge, both in the direction of its axis and in the diametral direction. Screws up to 2 inches diameter could be inspected on thread form and also measured on pitch, angle, and all diameters. Screws from 2 to 6 inches, for which another pair of centres was provided, could be treated likewise, except that the diameters could not be measured, the run of the diametral micrometers being limited to 2 inches. The method of obtaining

the "rake" of the light by inserting auxiliary lenses and throwing the image out of focus, was first introduced in the design of this machine. It should be noted that this method is apparently only approximate. In certain cases it has been found to fail, and a complete explanation of the effect has not yet been obtained.

This machine has also been manufactured in quantity by G. Cussons, Ltd. The first example was erected at the Laboratory in April 1918. Two others have since been installed at the Laboratory, and a number have been supplied to manufacturers of screw gauges. A description of it has been published in *Engineering*, 23rd and 30th August, and 6th September 1918. The machines, when first submitted, had need of considerable rectification, which was carried out partly in the Gauge Workshop, and partly by Dr. J. S. Owens, a volunteer assistant, who took great interest in this work, and who developed the methods of testing since applied to the machines.

The Institution of Mechanical Engineers.

EXTRAORDINARY GENERAL MEETING,

FRIDAY, 19TH NOVEMBER 1920.

An EXTRAORDINARY GENERAL MEETING was held on Friday, 19th November, at Ten Minutes to Six o'clock, the requisite quorum of thirty Members being present. Captain H. Riall Sankey, C.B., C.B.E., R.E., ret., *President*, in the Chair.

The RESOLUTION (*see* pages 961–2), which was passed at the Extraordinary General Meeting on 22nd October, was read by the Secretary and confirmed.

The Meeting then terminated.

PROCEEDINGS.

GENERAL MEETING.

19TH NOVEMBER 1920.

An ORDINARY GENERAL MEETING was held at The Institution, London, on Friday, 19th November 1920, at Six o'clock p.m., Captain H. RIALL SANKEY, C.B., C.B.E., R.E., (ret.), *President*, in the Chair.

The Minutes of the previous Meeting, held on 22nd October, were confirmed and signed.

The following Paper was read and discussed :—

"Sterilization of Water by Chlorine Gas"; by Captain J. Stanley Arthur, O.B.E., B.Sc., A.I.C., R.A.M.C. (T.F.), of London.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 97 Members and 36 Visitors.

Captain Arthur's Paper was also discussed at :—

Manchester, in the Engineers' Club, on Thursday, 25th November; Mr. H. P. Hill, in the Chair.

STERILIZATION OF WATER BY CHLORINE GAS.

By Captain J. STANLEY ARTHUR, O.B.E., B.Sc., A.I.C., R.A.M.C. (T.F.), of London.

The aim of all water purification for drinking purposes is to produce a clear, tasteless water free from harmful bacteria. The very best methods of filtration can only bring about a reduction of 98 per cent of the total number of bacteria present in the water. In order to remove the remaining 2 per cent of bacteria, and thus render the water perfectly safe, a process of sterilization must be carried out. This process also acts as a safeguard in case of a breakdown of a sand-filter.

Many methods have been devised to carry out the complete sterilization of water, and they can be divided into physical and chemical methods. The physical methods, which include sterilization by heat and by ultraviolet light, although quite efficient, are more difficult to operate and are more expensive than chemical methods. Chemical methods are cheap and comparatively easy to manipulate, and are capable of very exact operation. Chlorine, either as the free element or combined, as in bleaching powder, is the chemical which is most largely used. Bleaching powder, or chloride of lime, was first used to sterilize a supply of drinking water in 1897 at Maidstone where an epidemic of typhoid was raging. Its use was attended with very successful results, typhoid being very rapidly stamped out.

Chlorine, in the gaseous condition, although used in America to

a small extent for some time, has only come into general use during the last few years. The amount of chlorine, either as a gas or from bleaching powder, required to sterilize water is quite small. For a sedimented and filtered water less than half a part of chlorine per million parts of water is sufficient for complete sterilization, and for a crude water, for example, Thames water at Kew, only three to four parts per million are required, provided that this chemical is allowed to remain in contact with the water under treatment for not less than twenty minutes.

At the outbreak of war the only method of water purification that could be carried out in the field, other than that involving the use of acid sodium sulphate tablets, was embodied in the Water-Cart. In this apparatus water was pumped from the source, treated with aluminium sulphate with or without the addition of an alkali, filtered through a cloth-covered cylinder on which the aluminium hydroxide, produced by the hydrolysis of the aluminium sulphate, was deposited and which formed the real filtering medium. After filtration the water was treated with bleaching powder—chloride of lime—to produce sterilization. It was soon found that the amount of bleaching powder that was being added was often greatly in excess of that actually required to produce sterilization. Attempts were made to devise a simple method by which the amount of bleaching powder required to sterilize any water could be determined in the field. The first suggestion was made by Professor Sims Woodhead, and the actual details resulting in the fitting up of a case containing the necessary apparatus and chemicals with instructions for carrying out the test were worked out at the Royal Army Medical College under the direction of Sir William Horrocks (*See* Appendix, page 1149). With this test case, known in the Army as the "Case, Water Testing Sterilization," and the water-cart as the starting point, the whole of the great water purification scheme of the Army has been built up. That the methods adopted have been successful is seen from the fact that throughout the war there has been no epidemic of any water-borne disease.

The first advance upon the water-cart was the production of a type of water purification plant which sterilized water by a

continuous process at the rate of 125 gallons per hour, using bleaching powder as the sterilizing chemical. This was a distinct improvement over the water-cart which only worked intermittently. From this small type a much better and larger plant was devised, giving a continuous output of 400 gallons per hour and in which the excess of chlorine that was left in the water after sterilization was completed, was removed by means of a solution of sodium bisulphite. This plant was fitted up on a 3-ton motor lorry and a large number were sent to France and known as Nos. 1 and 2 Water Tank Companies. These companies had a number of water purification plants which, in addition to being able to sterilize water, could also remove poisons from it. A large number of tank or carrying lorries were also attached to these companies for the purpose of transporting the purified water.

It was felt that these plants had several disadvantages. The output of water was relatively low and there was a considerable amount of work entailed in preparing the solutions used in the process. Attempts were made to overcome these defects and finally, by the introduction of the use of chlorine gas, a new type of water purification plant was devised which has been adopted, with minor alterations to meet special conditions, as the standard of the British Army. The principle of this plant has been applied to all types of water purification plants in use in the field.

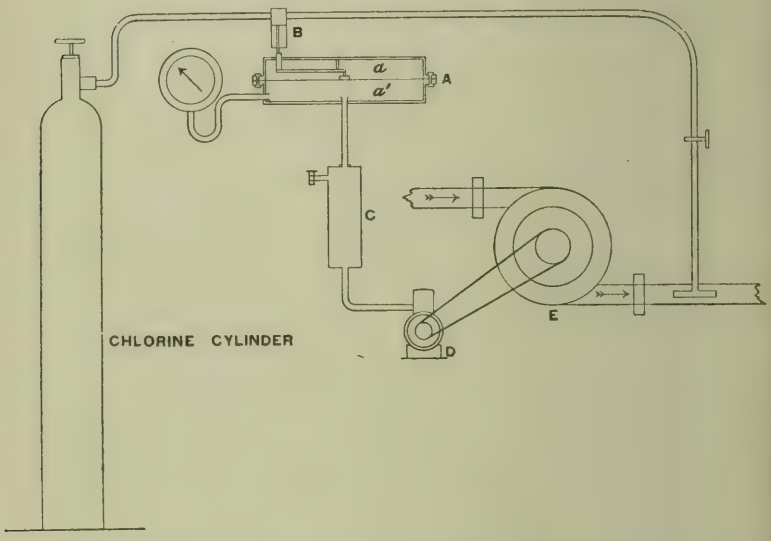
A considerable amount of work had been done in America on the question of sterilization of water by means of chlorine, and great difficulty had been experienced in devising a satisfactory method of administering this gas to water. In 1912 a patent was granted to Major Darnell, of the American Army, for an apparatus for the administration of chlorine gas to water for the purpose of sterilizing it.*

This apparatus, Fig. 1 (page 1130), consists of a cylinder of liquid chlorine connected to a pressure regulator A. This regulator controls the flow of chlorine from the cylinder by acting on a valve B by means of levers, the regulator itself being in turn controlled by the rate of

* American patent, No. 1007647, 31 Oct. 1912; Journal Amer. Public Health Assoc., Nov. 1911.

flow of the water that is being treated. The regulator consists of an iron case divided by a circular diaphragm, thus forming two similar compartments, *a* and *a'*. The diaphragm is connected at the top, by means of levers, to the easily adjusted valve B. The lower portion of the case, which is air-tight, is connected to a small compressor D through a reservoir C. This compressor is worked by means of a turbine E which is driven by the water that is being

FIG. 1.—*Chlorinator* (Darnell).



treated. As the water flows through the turbine, the compressor increases the pressure of the air in the lower portion of the regulator. This pressure will vary according to the rate at which the water is flowing through the turbine, and will thus act on the diaphragm and control the rate at which chlorine may pass through the valve B. Theoretically, the apparatus is automatically controlled, but difficulty was experienced in operating it successfully.

Leavett Jackson and the Electro Bleaching Gas Co. constructed apparatus to administer chlorine to water, but the chlorinating apparatus which has proved commercially successful is that made

by Messrs. Wallace and Tiernan, of New York, who, working upon the lines of the Darnell apparatus, have produced two types of chlorinators which have proved very successful in operation. Other attempts have been made to produce apparatus for the purpose of administering chlorine gas to water, but up to the present those constructed by Wallace and Tiernan appear to be the best and most accurate.

The two types of apparatus manufactured by Wallace and Tiernan are the same in principle but differ in that, in the Direct-Feed type, chlorine gas is added directly to the water under treatment, while in the Solution-Feed type the gas is first dissolved in water and this solution added. Both types have as an object the delivery of a continuous supply of chlorine to water at a known indicated uniform rate, which is independent of any changes of pressure of the chlorine in the containing cylinder. The first instrument—a Direct-Feed type—was brought to England in August 1916 and placed at the disposal of the War Office by Messrs. United Water Softeners, Ltd.

An experimental plant was constructed and exhaustive tests were made upon the canal water at Brentford, Middlesex, with the object of determining if chlorine were an efficient sterilizing chemical and if the apparatus were satisfactory. Many of these tests extended over a continuous period of 72 hours and the results of one test are given in the Table (pages 1151–3). At the conclusion it was found that:—

(1) Chlorine is a most efficient chemical for sterilizing water.
(2) The apparatus is extremely satisfactory, easy to manipulate and accurate.
(3) Water so treated has a far less marked taste than water similarly treated with bleaching powder.

During the tests it was suggested that the use of sulphur dioxide gas to remove the excess of chlorine left in the water after completion of sterilization would render the process more efficient in that the purified water would be free from the slight taste imparted to it by chlorine, and would render the removal of this taste much easier than would the use of a solution of sodium bisulphite.

This method has been adopted as standard for all types of water purification plants in the Army, except very small ones which are too small to allow of this process to be economically used. The Direct-Feed type of Wallace and Tiernan chlorinator was adopted as standard.

Direct-Feed Chlorinator (Fig. 2, Plate 21, and Figs. 3 to 6).—The

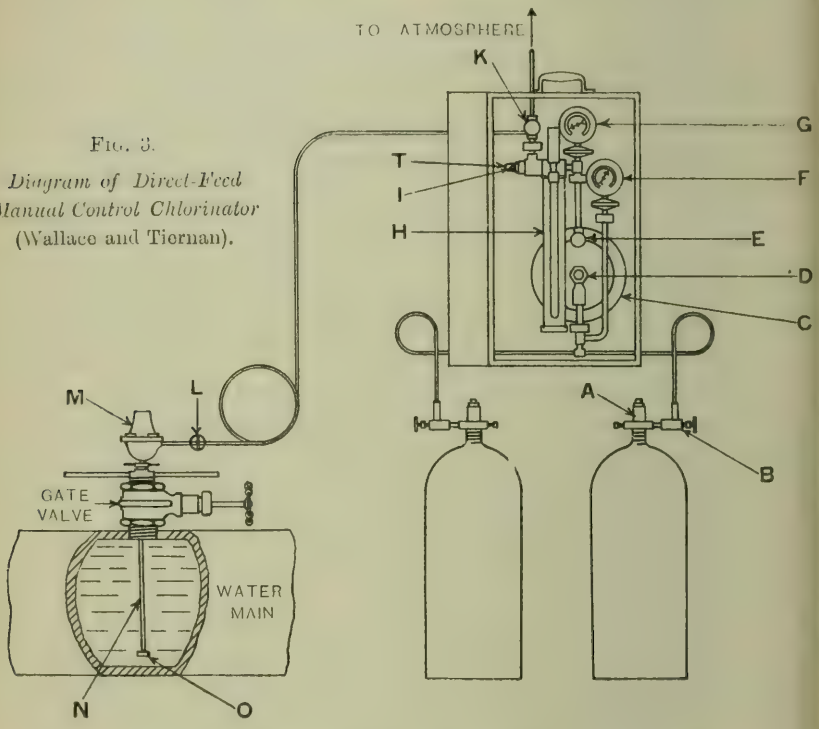


FIG. 3.

Diagram of Direct-Feed Manual Control Chlorinator (Wallace and Tiernan).

apparatus is essentially one which meters chlorine gas and which at the same time delivers the gas at a constant pressure. Chlorine is stored in steel cylinders as a liquid and the pressure within such a cylinder will depend upon the temperature at which the cylinder happens to be. The pressure of liquid chlorine at 0° C. is 54 lb. per square inch and at 50° C. (122° F.) it is 216 lb. per square inch. The pressure registered within a cylinder of liquid chlorine is the

FIG. 4.—*Compensator* (C, *Fig.* 3) *in Section, separated. Chlorinator* (Wallace and Tiernan).

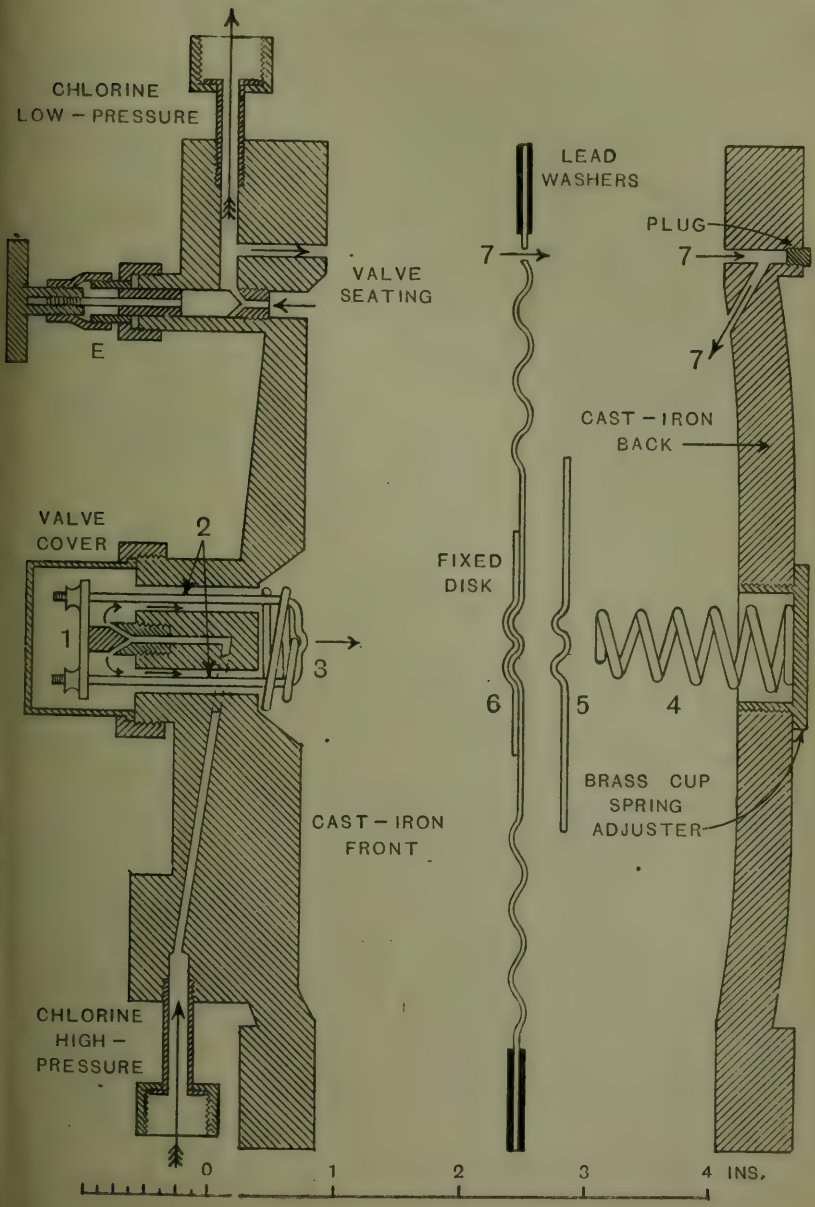


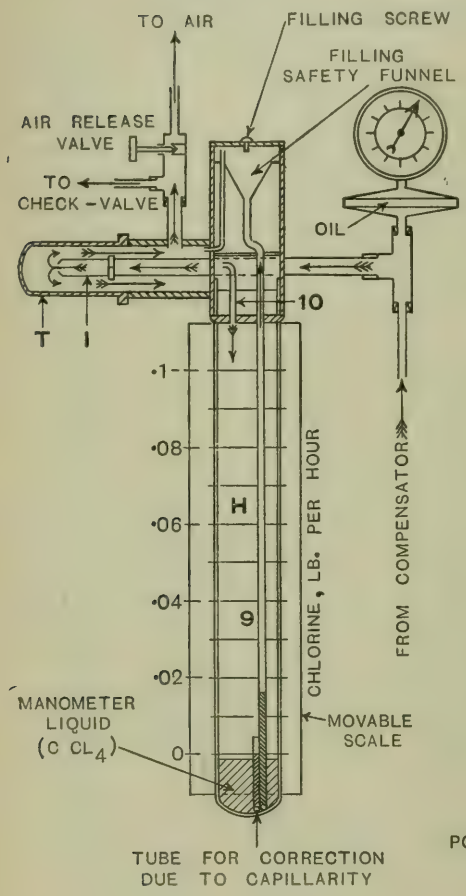
FIG. 5.—*Orifice* I, *and Manometer* H.

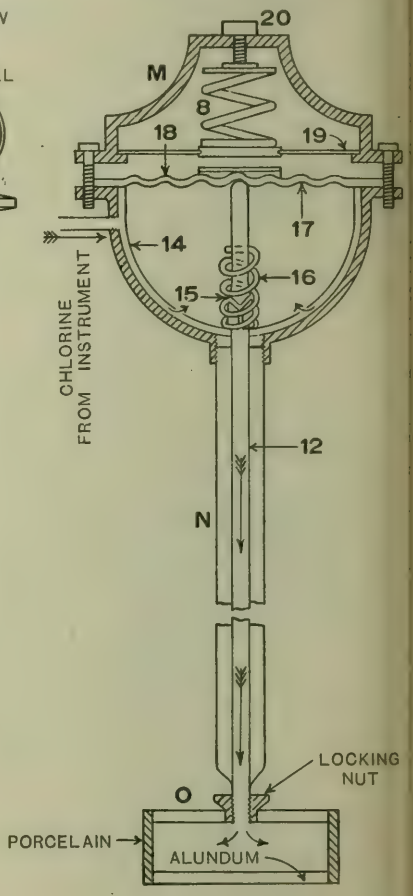
FIG. 6.—*Check-valve* M, *and Diffusor* O.

Chlorinator (Wallace and Tiernan).

Scale : ⅓ approx.

Scale : Half-size. (Separated and in part section.)





pressure which the vapour of liquid chlorine, that is, chlorine gas exerts while in contact with liquid chlorine at the temperature of the cylinder and its contents. A rise in temperature will produce a rise in pressure and vice versa.

If gaseous chlorine is allowed to escape, by opening a valve on a cylinder of liquid chlorine, some of the liquid must evaporate to account for this escape. This will affect the pressure of the gas in the cylinder, for liquid chlorine is a bad conductor of heat and consequently most of the latent heat required to evaporate it will be obtained first from the liquid chlorine itself and not from the surrounding atmosphere, and as a result the temperature of the liquid chlorine inside the cylinder will fall and thus produce a fall in pressure. The density of chlorine will also increase with a fall of temperature, and consequently the volume of chlorine gas that may leave a cylinder is not a direct measure of its mass.

The Wallace and Tiernan Chlorinator, Fig. 2, Plate 21, is actually a reducing valve and meter combined and consists of three main portions:—

(1) The Compensator, in which alterations of pressure in the cylinder are compensated, Fig. 4.
(2) The Metering or flow-measuring apparatus combined in the Orifice, Scale, and Manometer, Fig. 5.
(3) The Check-Valve—or back-pressure valve—and Diffusor, Fig. 6.

Compensator: Explanation of working, Fig. 3.—Under normal conditions when the instrument is started, the valve on the cylinder A and the auxiliary tank-valve B, control-valve E, blow-off valve K, and auxiliary valve on check valve L, are shut. The auxiliary valve L fitted to check valve M and main tank-valve A are opened, the control-valve E being kept closed. The auxiliary tank-valve B is opened slowly. Chlorine now enters the compensator C through the small needle-valve (1, Fig. 4) and passes down the two holes (2) and fills the space between the front portion of the compensator and the silver diaphragm (6, Fig. 4). The pressure in this space increases and forces back the silver diaphragm (6) and the

strengthening disk (5) against the spring (4) and at the same time allows the spring (3) to close the needle-valve (1).

The pressure of the chlorine in the cylinder is indicated by the tank pressure-gauge F, Fig. 3. If the control valve E is slowly opened, chlorine will pass through this valve and slowly build up a pressure which is registered on the back-pressure gauge G. This pressure will be exerted on the back of the silver diaphragm (6, Fig. 4) as there is a small hole (7) drilled through the apparatus for this purpose. During this operation the control-valve E is only opened sufficiently to cause the liquid in the manometer tube H (Fig. 5) to rise in the small inner tube (9) and remain in sight. If opened too much, the liquid in the manometer tube will be driven up into the space at the top, and it may get into the compensator or orifice cap I and T.

As chlorine passes through the control-valve E, the pressure on the front side of the diaphagm (6) will fall, consequently the pressure on the back side of this diaphragm—due to a spring (4) and the back pressure—will cause the diaphragm (6) to press on the needle-valve (1) and thus allow more chlorine to enter. As soon as the back and front pressures are equal, a state of equilibrium is maintained in the compensator. Any chlorine passing out of the compensator will tend to increase the pressure on the check-valve M (Fig. 6) and more chlorine will consequently pass through the needle-valve (1) due to the slight breathing movement of the silver diaphragm, the chlorine entering the compensator from the main cylinder at the same rate as it passes through the check-valve to the diffusor. Thus a steady flow of chlorine is maintained, the chlorine leaving the apparatus at a constant pressure set up by the check-valve M.

Manometer and Orifice and Scale (Fig. 5).—The outer glass tube of the manometer H is connected by means of the small tube (10) to the orifice I which is made of glass and which varies in size according to the amount of gas that the instrument is required to pass, and the small tube (9) to the orifice cap T. As chlorine flows from the compensator, it meets the orifice and is necessarily checked in its flow, and subsequently a pressure is set up before

the gas passes through the orifice. The difference in the pressure of the chlorine before and after it has passed through the orifice is proportional to the flow of the gas, as in a Venturi water-meter. Since the back pressure set up by the check-valve is constant, the chlorine will be passing from the orifice at a steady pressure and will therefore be unaffected by any change of pressure to which the chlorine may be subjected. The pressure set up by the flow of the chlorine through the orifice is indicated by the height of the liquid in the manometer tube, and this height is read by means of an adjustable scale which has been graduated, experimentally, for the orifice in question, in pounds of chlorine per hour. Any desired quantity of chlorine can be allowed to pass from the instrument, within the range that the orifice can pass, by opening or closing the control-valve E, Fig. 3, on the compensator C.

Check-Valve (Fig. 6).—The check-valve consists of a silver-plated brass or copper stem N through which runs a silver tube (12). To the open end of this tube is attached the diffusor O, which consists of a porcelain ring into which two disks of alundum are cemented. The other end is attached to a perforated silver hemisphere (14) which fits inside the main portion of the valve, and is fitted with a needle-valve (15) which is kept open by a spring (16). Closing this hemisphere is a silver corrugated disk (17) with a similar strengthening disk of copper (18) on the top of it. Acting on this is a spring (8) to which is fitted an adjusting screw (20). This spring acts on a segmented disk (19) which in turn acts on the two diaphragms and closes the needle-valve. No chlorine can pass out of the check-valve until the pressure within is sufficient to overcome the pressure of the spring (8) and so lift the needle-valve. This pressure is the back pressure and is usually set at 25lb. per square inch.

By means of the apparatus the chlorine enters the compensator at any pressure and, after passing through it to the orifice, it is metered and leaves the apparatus at a constant pressure and is forced into the water through the diffusor which breaks up the gas into very small bubbles. The amount of chlorine passing through

the apparatus is regulated by means of the control-valve E, Fig. 3, and when once set will continue to deliver chlorine at the set rate until the cylinder is empty. For a temporary stoppage, it is only necessary to close the auxiliary tank-valve B and on restarting,

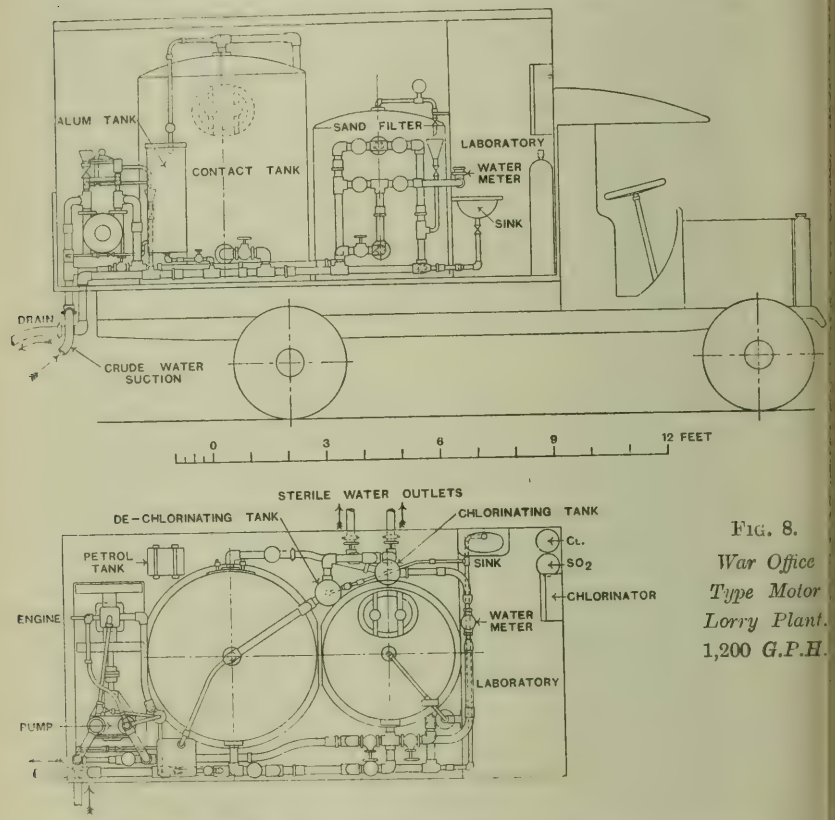


FIG. 8.
War Office Type Motor Lorry Plant.
1,200 *G.P.H.*

to open this valve. The apparatus can be emptied of chlorine by means of the blow-off valve K.

It is absolutely essential that moisture should be kept from getting inside the apparatus, as although dry chlorine has no effect, moist chlorine will rapidly corrode the metal parts of the apparatus. It is also necessary to keep the cylinder of chlorine at about the same temperature as the chlorinator, as at low temperatures

chlorine under pressure liquefies very easily, and if the instrument is colder than the cylinder, liquid chlorine will collect in it and render the flow of chlorine unsteady.

The Solution-Feed type of apparatus, Fig. 7, Plate 21, differs from

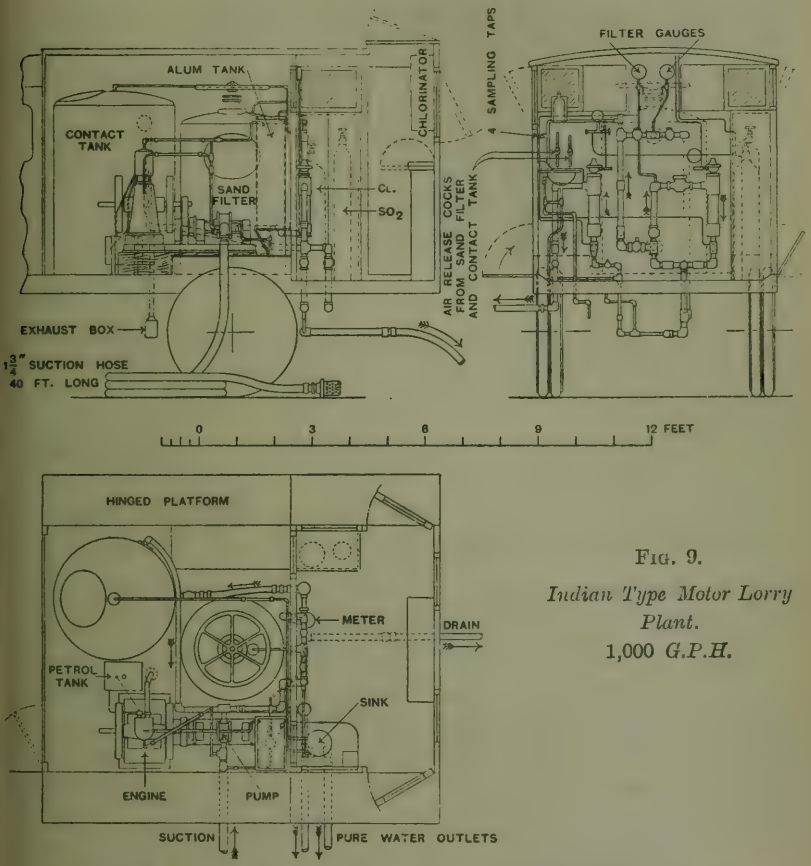


Fig. 9.

Indian Type Motor Lorry Plant.
1,000 *G.P.H.*

the Direct-Feed type in that the chlorine, after it leaves the compensator, passes to a bubble meter in which the bubbles of chlorine are seen and counted and are dissolved in water. The rate of flow of the chlorine is determined by the rate of the bubbles, and regulated by means of the control-valve on the compensator.

After the bubbles of chlorine have dissolved in the water that is led to the bubble meter and which is under constant agitation, it is injected into the water that has to be sterilized. This type of instrument has the advantage over the Direct-Feed type in that the actual chlorine that is being used is seen, and that it can be used to deliver smaller amounts of chlorine than the Direct-Feed type. It is, however, slightly more complicated and requires more care in fitting up, but it is if anything more accurate than the Direct-Feed.

The Direct-Feed type has been adopted throughout the water purification plants in use in the Army, and they have given every satisfaction. The makers guarantee an efficiency and accuracy of at least 96 per cent, and on several tests the accuracy has been almost 100 per cent.

The purification plants in the Army in which the chlorine-sulphur dioxide process has been adopted as standard can be divided into three classes:—

(1) Portable plants built on motor-lorries, Figs. 8 and 9, and Figs. 10–14, Plates 22–23.
(2) Portable plants built on barges, Fig. 15 (page 1142).
(3) Stationary or land plants, Fig. 16 (page 1143).

The first class is primarily for use with an army moving into occupied territory, in which the usual sources of water have been destroyed or rendered useless. The second serves to some extent the same purpose but on a larger scale, and the third is the standard type for supplying water to troops in the rear of operations and for replacing the water supply of towns.

The process of purification is the same for all three types of plant, and can be divided into five main operations:—

(1) Coagulation of suspended matter by means of aluminium sulphate solution, or, if necessary, with this chemical and an alkali.
(2) Sedimentation of the water so treated.
(3) Filtration of the water after coagulation and sedimentation.

(4) Sterilization, using chlorine gas.

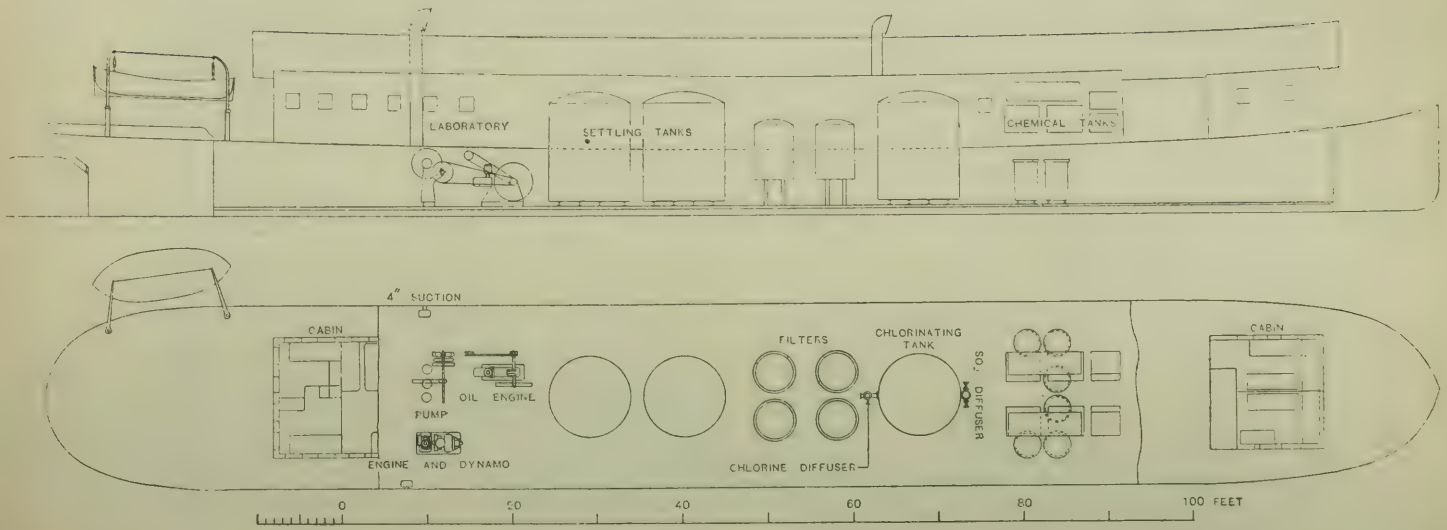
(5) Dechlorination, using sulphur dioxide gas.

Under some circumstances it may not be necessary to treat chemically or sediment the water before filtration, but whenever the crude water contains a large amount of fine material in suspension, or is coloured by iron or clays, a preliminary chemical treatment is essential.

The five operations are carried out in slightly different ways by the three types of plants, each adopting that which is most convenient. Coagulation and sedimentation are carried out by the motor portable plants in canvas dams, but in the other types pretreatment tanks form part of the plants. If it is necessary to pretreat the water, the required amount of aluminium sulphate, or alum, together with lime or soda if the water is very soft, is added to the water and well mixed. After standing for some time the water clears and the suspended matter falls to the bottom with the aluminium hydroxide which has been formed by the hydrolysis of the aluminium sulphate. The cleared water is then led to the filters in such a way that the sediment in the pretreatment tanks remains undisturbed. The filters, except those constructed by Ransome ver Mehr, consist of cylindrical iron tanks, filled with sharp clean sand resting on a bed of graded gravel, fitted with some arrangement for stirring the sand mechanically, and so constructed that water can be admitted from the top or the bottom.

Filtration always takes place through the sand from the top downwards. It is essential, however, that the filters should be completely filled with water from the bottom upwards, in order to remove all air from the sand, and to form a solid bed of it free from possible cracks and air-channels. When this has been done, the direction of the flow of the water is reversed and filtration commenced, the water passing in at the top of the filter and out at the bottom. The object of the mechanical stirring arrangement and the arrangement for sending the water up through the sand is to enable this to be backflushed or cleansed after it has been in use for some time, thus removing the matter which has been filtered

FIG. 15.—*General Arrangement of Filtration Plant on Barge. Capacity,* 8,000 *G.P.H. Filter Type "Ransome."*



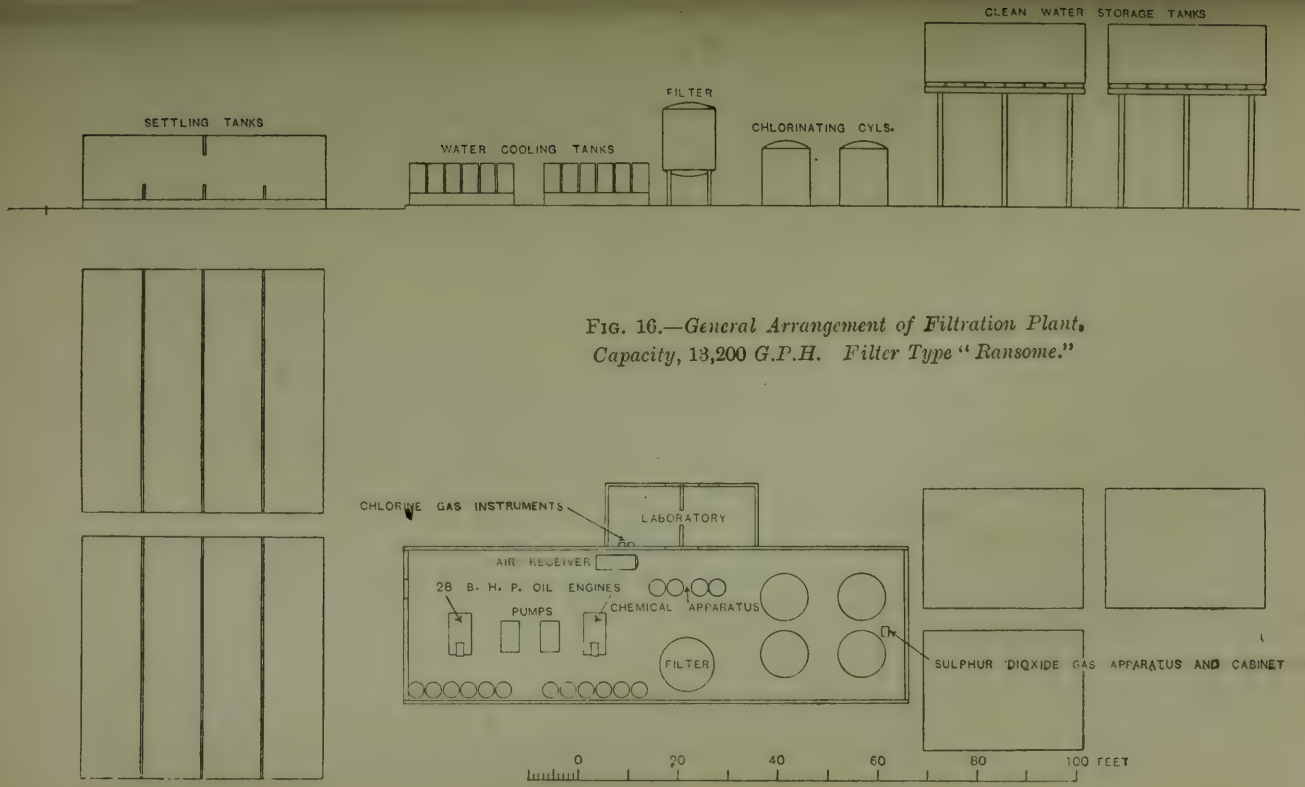


FIG. 16.—*General Arrangement of Filtration Plant, Capacity,* 13,200 *G.P.H. Filter Type "Ransome."*

out on the top of the sand, which gradually causes the filtration pressure to increase.

In the Ransome filter, used on some barge and stationary plants, a modification of the ordinary filter is used, a mechanical stirring arrangement being unnecessary as the surface of the sand is constantly shifting and being replaced by sand which has been automatically washed. In the earlier type of motor-lorry plant, in which weight was necessarily restricted, a mechanical stirring arrangement was not used, and backflushing of the filter had to be carried out with crude water. This made it necessary, on starting the filter, to allow the filtered water to pass to waste, as it had not been filtered right through the sand. In the other types of plants this was rendered unnecessary, as sterilized water is used to backflush the sand-filters.

A good sand-filter should remove all suspended matter and produce a clear water with a considerable reduction of the number of bacteria in it. It will work best if there is present on the surface of the sand a layer of aluminium hydroxide. If the water has been chemically treated, some of the aluminium hydroxide formed is carried on to the bed of the sand-filter from the settling tanks, but if it has not been so treated, then a solution of aluminium sulphate is injected into the water before it enters the sand-filter. This solution is hydrolysed by the water and the aluminium hydroxide deposited on the surface of the sand as filtration proceeds. The filter-bed thus formed clears the water to a very much greater extent than a plain untreated sand-filter could do and, at the same time, it will reduce the number of bacteria in the water very considerably.

After filtration has been going on for some time, the pressure on the filter-bed increases, and filtration becomes more difficult. A point is reached when the sand-filter must be backflushed to remove the layer of sedimentary matter which has collected on the top of the sand-filter. Before filtration can be commenced again the filtering surface has to be reformed with aluminium hydroxide. After filtration the water is then sterilized by means of chlorine. Some plants, especially those which have been converted to use

chlorine gas, can be used for sterilization with bleaching powder in case the chlorine method should break down.

The amount of chlorine to be added is indicated by means of the test described in the Appendix (page 1149), the complete apparatus and chemicals for which are contained in a case supplied to the troops, and known as "Case, Water Testing Sterilization," unless the water has been examined bacteriologically. This indicated amount of chlorine is administered by the Wallace and Tiernan Chlorinator, which is adjusted to deliver the correct amount of chlorine for the particular rate of output of the plant. The apparatus is graduated in pounds of chlorine per hour, and this is converted into parts of chlorine per million of water by means of a conversion scale (page 1150). The adjustment of the flow of chlorine is carried out as described previously.

The filtered water is thus chlorinated and partly sterilized, but complete sterilization takes place after the water has been in contact with chlorine for not less than twenty minutes. The period of contact is obtained by allowing the chlorinated water to pass through a large tank or series of tanks. These tanks are fitted with baffles to prevent short circuiting of the water. During the period of contact some of the chlorine is absorbed, and at the completion of this time the water is completely sterilized as is shown by obtaining negative results by the MacConkey and Neutral Red Agar tests. The water, although filtered and free from bacteria, contains some chlorine, and as a consequence has a slight taste. This taste can be completely removed by the addition of sulphur dioxide, the chlorine reacting with this gas to produce hydrochloric and sulphuric acids, or chlorides and sulphates, which, at the very great dilution at which they are present, cannot be detected by taste.

The sulphur dioxide is added to the water by means of a simple apparatus which consists essentially of a check or back-pressure valve, to prevent the water under treatment entering the apparatus, and a fine adjustment valve for regulating the flow of the gas. A pressure-gauge is fitted to indicate the pressure of the sulphur dioxide in the cylinder. The amount of sulphur dioxide to be

added is determined by a simple chemical test which is repeated from time to time and, if necessary, any alteration of the fine adjustment valve made. The test is made by adding a solution of potassium iodide and starch to a small quantity of the water after it has been treated with sulphur dioxide. A blue colour is produced by the chlorine, and the amount of sulphur dioxide that is being added is adjusted until only that colour is produced, which indicates that less than half a part of chlorine is present in a million parts of the treated water. This test is extremely delicate, for a definite blue colour is obtained with 0·2 part of chlorine per million.

The small amount of chlorine that is left in the water is for the purpose of preserving the sterility of it during the transit from the purification plants to the troops actually using it. If the water is required for use on the spot, the amount of chlorine left in can be reduced to an almost negligible quantity. On some of the larger plants a rather more elaborate dechlorinating instrument is used, differing only in detail to the above-mentioned type.

In field operations, the water which has been purified is either delivered to storage tanks, and from these to pipe-lines or, as is the case with the mobile purification plants, to tank-lorries or water-carts. The small amount of chlorine that is purposely left in the water generally disappears by the time it reaches the troops, and consequently no taste of this chemical can be detected. It has been found possible, under some circumstances, to deliver water direct to the petrol tins used for carrying water to the trenches, thus saving a great deal of transport and its attendant difficulties, a matter of considerable importance in warfare.

Experience gained in the late War has shown that water purification installations using chlorine as the sterilizing chemical are extremely efficient, simple, and cheap to operate, and that the water after treatment is without the characteristically objectionable taste which is associated with water that has been sterilized by means of chloride of lime. There is no question that, for installations of even a moderate size and even quite small ones that are in almost constant use, the chlorine-sulphur dioxide

process is the best and most efficient one that can be adopted. Chlorine is cheap, it is easily transported and stored, and there is no loss or deterioration occasioned by even very long storage. The process entails very little labour for making solutions, and the manipulation is extremely simple and easily learnt.

For very small plants, and those which are not in frequent use, the initial cost of a chlorine-sulphur dioxide installation is comparatively high, and for this reason chlorine will never replace entirely chloride of lime as a sterilizing chemical for water. Chloride of lime, however, has one very serious disadvantage in that it is very easily decomposed by even a moderate temperature, and very great trouble was experienced in the early days of the War in providing a supply of sterilized water for the troops engaged in operations in the East. As soon as the chlorine-sulphur dioxide process was introduced, this difficulty was, to a very great extent, overcome, but the process could not be economically applied to small plants which gave an output of only a few gallons per hour.

As a result of experiments undertaken with the object of producing a sterilizing chemical which was not easily decomposed by heat a new substance was introduced. This chemical is known as bromine bleaching powder,* and is very similar in properties to chlorine bleaching powder, except that it is not decomposed at temperatures as high as 100° C. Bromine bleaching powder imparts a less objectionable taste to water than ordinary bleaching powder and is quite an efficient sterilizing chemical.

From this survey of the water supplies of the Army, it is evident that a supply of sterilized water can be maintained under almost any possible conditions by the use of one or other of the various types of water purification plants mentioned. So successful has the process been that new plants have been ordered for use in the East, Fig. 9 (page 1139). These are lighter and more compact than the ones used in France, and are even simpler to manipulate and embody many small improvements in design which have been

* British Patent No. 14661/18.

found to be desirable as a result of experience gained on active service in the War.

This Paper would be quite incomplete if the invaluable work done on the subject of Water Purification for the Army by Colonel Sir William Horrocks, K.C.M.G., C.B., M.D., and his Advisory Board was not fully acknowledged and emphasized. The work done by this Advisory Board of the Army Medical Service contributed to an enormous extent to the magnificent standard of health of the Army during the War. The whole of the work on Water Purification was under the direct control and personal supervision of Sir William Horrocks, and this Paper only deals with a portion of this work, but it will serve to indicate what has been done to safeguard the water supply of the Army during the Great War.

The Author is indebted to Messrs. The United Water Softeners, Ltd., for their kindness in lending several of the blocks and photographs used for illustrating this Paper.

The Paper is illustrated by Plates 21–23, 9 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

Description and Method of Using the "Case, Water Testing Sterilization," in connexion with Chlorine Gas.

Description of Contents.

The contents of the case are as follows :—

Six white-enamelled cups, each holding $\frac{1}{3}$ pint of water when filled to the brim.

One black-enamelled cup with mark on the inside.

Two metal spoons, each holding 2 grammes when filled with bleaching powder level with the brim.

One stock bottle of zinc iodide and starch test solution and one dropping bottle. Three drops of the solution give a definite colour with water containing one part per million of free chlorine.

Six glass tubes or pipettes, each of such dimensions that a drop of standard bleaching powder solution delivered by it, when held in a vertical position, into a white cup filled with water gives a dilution of one part per million of free chlorine.

Four glass stirring rods, twelve pipe cleansers and two copies of instructions.

Method of Using.

Crude water is generally used. The test is best carried out while the plant is being prepared for work. The test takes about half an hour to carry out.

1. A standard solution of bleaching powder is prepared in the black cup by putting into it one level spoonful of good bleaching powder, making it into a paste with a little water by stirring it with a glass stirrer and carefully breaking up all lumps. More water is added to the paste and the black cup filled with water to the mark on the inside. This is stirred vigorously and the glass stirrer left in the black cup. One of the pipettes is put into the solution, which is never clear as it contains lime in suspension.

2. The six white cups are filled with the water to be tested to within $\frac{1}{2}$ inch of the top.

3. Drops of the standard bleaching powder solution from the pipette are added to the water in the white cups so that they contain 1, 2, 3, 4, 5 and 6 drops respectively. Each cup is thoroughly stirred with a clean rod, and

this rod is left in one of the cups. The cups are allowed to stand for half an hour.

4. After half an hour, three drops of the zinc iodide and starch solution are added from the dropping bottle, and each cup is stirred with the rod that was left in one of the cups.

5. Some of the six white cups show no colour, while some will show a blue colour. The first cup which shows a blue colour, that is the one containing the smallest number of drops, is noted. If cups 1, 2 and 3 show no colour and 4, 5 and 6 show a blue colour, then cup number 4 is the one to be noted. The water will therefore require four parts of chlorine per million to sterilize it. If none of the cups show a blue colour, then the cups are washed out and the test performed again with 6, 7, 8, 9, 10, 11 and 12 drops of the bleaching powder solution in the cups.

6. Each drop of the bleaching powder solution in a white cup of water corresponds to one part per million of chlorine.

7. It is to be noted that only if the bleaching powder is fresh and good will this test accurately agree with the amounts of chlorine gas required for sterilization. It serves, however, as a guide for the amount of chlorine to be added to the water by means of the Wallace and Tiernan Chlorinator.

Conversion Table.

SHOWING LB. OF CHLORINE PER HOUR.

Parts per Million.	Gallons of water per hour.										
	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400
1	0·004	0·005	0·006	0·007	0·008	0·009	0·01	0·011	0·012	0·013	0·014
2	0·008	0·01	0·012	0·014	0·016	0·018	0·02	0·022	0·024	0·026	0·028
3	0·012	0·015	0·018	0·021	0·024	0·027	0·03	0·033	0·036	0·039	0·042
4	0·016	0·02	0·024	0·028	0·032	0·036	0·04	0·044	0·048	0·052	0·056
5	0·02	0·025	0·030	0·035	0·04	0·045	0·05	0·055	0·06	0·065	0·07
6	0·024	0·03	0·036	0·042	0·048	0·054	0·06	0·066	0·072	0·078	0·084
7	0·028	0·035	0·042	0·049	0·056	0·063	0·07	0·077	0·084	0·091	0·098
8	0·032	0·04	0·048	0·056	0·064	0·072	0·08	0·088	0·096	0·104	0·112
9	0·036	0·045	0·054	0·063	0·072	0·081	0·09	0·099	0·108	0·117	0·126
10	0·04	0·05	0·06	0·07	0·08	0·09	0·1	0·11	0·12	0·13	0·14

Experimental Test on the Chlorination of Water by means of the Wallace Tiernan Chlorinator. Brentford, 12th–15th Sept. 1916.

All chlorine was removed after sterilization by means of sulphur dioxide.

Time of Test.	Rate of Flow. Galls. per hour.	Wallace Tiernan Gauges.			Chlorine—parts per milllion		
		Tank.	Back.	Manometer Level.	Injected.	A After 10 mts.	B After 30 mts.
12/9/16							
2.30 p.m.	540	74	19·5	0·8	4·7	—	—
3.40 ,,	770	70	19·5	0·57	3·6	3·0	2·7
4.30 ,,	720	72	19·5	0·56	3·5	3·5	3·3
6.0 ,,	600	75	20	0·55	3·5	3·2	3·2
8.30 ,,	720	75	19·5	0·5	3·4	3·2	3·2
10.30 ,,	640	75	19·5	0·525	3·5	3·3	3·3
13/9/16							
1.0 a.m.	675	72·5	19·2	0·52	3·5	3·3	3·3
3.0 ,,	675	71	19·1	0·52	3·5	3·3	3·3
5.0 ,,	675	71	19·1	0·53	3·5	3·3	3·3
7.0 ,,	675	72	19·4	0·54	3·5	3·3	3·3
9.15 ,,	675	77	19·75	0·55	3·5	3·3	3·3
11.0 ,,	640	82	19·75	0·5	3·5	3·3	3·3
2.0 p.m.	640	82	20	0·54	3·5	3·3	3·3
4.0 ,,	640	77	20	0·53	3·5	3·3	3·3
14/9/16							
5.30 p.m.	720						
6.0 ,,	720	63	20	0·75			
7.0 ,,	720	61	19	0·75	5·15	2·13	1·7
8.30 ,,	720	57·5	18·6	0·79	4·1	1·77	0·9
10.0 ,,	720	56	18·5	0·8	4·1	1·77	1·0
11.30 ,,	720	55	18·5	1·06	5·3	3·1	1·95
15/9/16							
1.0 a.m.	720	52	18·5	1·07	5·8	3·9	1·95
3.0 ,,	720	50	18·5	1·07	5·9	3·8	3·2
5.30 ,,	720	49	18·3	1·08	6·2	2·1	2·1
7.0 ,,	720	48	18·1	1·1	6·2	2·2	1·6
9.0 ,,	720	52	18·75	1·15	6·2	2·6	2·1
11.0 ,,	720	65	19·1	0·55	4·7	4·4	3·4
1.0 p.m.	720	68	19·1	0·55	4·8	3·8	1·77
2.30 ,,	720	70	19·2	0·55	4·4	3·8	1·7
3.30 ,,	675	70·5	19·5	0·35	2·4	2·0	1·5
4.30 ,,	640	70·5	19	0·17	1·4	1·2	1·2
5.30 ,,	640	70·5	19	0·15	1·2	1·1	1·1

Remarks.

13/9/16 (4.30 p.m.) Breakdown of pumping plant.
14/9/16 (5.0 p.m.) Started again after repairs.
,, (6.0 p.m.) Commenced chlorinating.
,, (10.30 p.m.) Chlorine increased.
15/9/16 (9.45 a.m.) Chlorine reduced.
,, (3.0 p.m.) Chlorine reduced.
,, (4.0 p.m.) Chlorine reduced.
,, (5.30 p.m.) Test stopped.

Experimental Test on the Chlorination of Water.—Continued.

Time of MacConkey Test.	MacConkey Test 50 cm.³ incubated at Brentford. Date and Time of Inspection.															
	14/9/16 11 a.m.		15/9/16 10 a.m.		16/9/16 2 p.m.		18/9/16 11 a.m.		19/9/16 3 p.m.		21/9/16 11 a.m.		22/9/16 11 a.m.		23/9/16 11 a.m.	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
4.30 p.m.		+														
6.0 „	+	−	+	+												
9.0 „		−		+												
11.0 „		−		−		−		−		−		−		−		−
13/9/16																
1.30 a.m.		−		−		−		−		−		−		−		−
3.0 „		−		−		−		−		−		−		−		−
5.30 „		−		−		+										
7.30 „		−		−		−		−		−		−		−		−
9.45 „		−		−		+										
11.30 „	−	−	−	−	−	−	+	−		−		−		−		−
2.15 p.m.	−	−	−	−	−	−	+	−	+	+						
4.30 „	−	−	−	−	−	−	−	+	−	+	−		−		−	

	16/9/16 2 p.m.		17/9/16 3.30 p.m.		18/9/19 11 a.m.		19/9/19 2 p.m.		21/9/19 11 a.m.		22/9/19 11 a.m.		23/9/19 11 a.m.	
7.20 p.m.	−		−		+									
8.45 „	−		−		−		+							
10.30 „	−	−	−	−	−	−	−	−	−	−	−	−	−	−
11.45 „	−		−		−		−		−		−		−	
15/9/16														
1.0 a.m.	−	−	−	−	−	−	−	−	−	−	−	−	−	−
3.0 „	−		−		−		−		−		−		−	
5.0 „	−	−	−	−	−	−	−	−	−	−	−	−	−	−
7.0 „	−		−		−		−		−		−		−	
9.0 „	−	−	−	−	−	−	−	−	−	−	−	−	−	−
11.0 „		−		−		−		−		+				
1.0 p.m.		−		−		−		−		−		−		−
2.50 „		−		−		−		−		−		−		−
4.0 „		−		−		−		−		−		−		−
4.45 „	−	−	−	−	+	−	+	+						
5.30 „		−		+		+								

For REMARKS, *see next page.*

Remarks.—The following samples were taken, and sent to R.A.M. College:—

12/9/16	(6.30 p.m.)	Two samples. Both reported sterile.
,,	(11.0 p.m.)	,, ,, ,, ,, ,,
13/9/16	(3.0 a.m.)	One sample. Reported sterile.
,,	(12.0 noon)	,, ,, ,, ,,
,,	(3.30 p.m.)	Two samples. One reported sterile, one non-sterile.
14/9/16	(12.0 midnight)	One sample. Reported sterile.
15/9/16	(7.15 a.m.)	,, ,, ,, ,,
,,	(11.30 a.m.)	,, ,, ,, ,,
,,	(12.30 a.m.)	,, ,, ,, ,,

Discussion in London.

The PRESIDENT said his first duty was to ask the members to pass a very hearty vote of thanks to the Author for his admirable Paper.

The Motion was carried with applause.

The PRESIDENT said the actual sterilization of water did not concern the mechanical engineer (except of course when he had to drink it), but he had to understand the principles on which that sterilization was effected, otherwise he could not design nor appreciate the machinery used for the purpose. The Author had given the principles, and had explained and illustrated the machines in his Paper, and he (the President) hoped there would be a good discussion.

Dr. SAMUEL RIDEAL said he was sorry he was the first speaker on the Paper, for the reason that the subject matter was more mechanical, as the President had said, than chemical. He had been a chemist and a bacteriologist all his life, and therefore did not feel quite competent to open the discussion. He very much regretted the absence of Sir William Horrocks, who knew more about the

Dr. Samuel Rideal.)

actual operations of chlorine sterilizers during the War probably than anyone else, and he had hoped he would have been able to open the discussion. The Author had said that the subject was novel, and had traced the early history back to the time of the Boer War. It was true that, during the Boer War, chlorine was not used for sterilizing purposes, but it had been used for sterilizing water long before that period, and bromine, which the Author also referred to in connexion with the bromine bleaching powder, had also been used for sterilizing water before that date. In fact, some of the earlier work was done shortly after the cholera epidemic in Altona, which was some fifteen years earlier, when experiments were conducted in using bleaching powder for sterilizing the effluent water from the emigrant station at Hamburg. The first practical use of chlorine for sterilizing water on a large scale was in connexion with the Maidstone epidemic, when Sir Sims Woodhead used bleaching powder for sterilizing the water mains.

He regretted that Sir Alexander Houston was not present that evening, as he had taken a great interest in the problem of utilizing chlorine and bleach for sterilizing water. In the Lincoln epidemic —which he did not think the Author had mentioned—in 1905, which was after the Boer War, chlorine was used for sterilizing the water supply by him, so that experience had been gained before the water problem became acute in connexion with the Army. He himself had seen in Philadelphia in 1912 Major Darnell's apparatus, which was one of the earliest forms of apparatus for using liquid chlorine as apart from bleaching powder for sterilizing. That was demonstrated before the International Congress for Hygiene and Demography which was held in Philadelphia in that year. The developments of the Darnell plant which had been shown that evening of course came rather late in the War, and one would have thought that the Americans, having had that practical experience in chlorine sterilization on a large scale for many years, would have been able to put forward their plant in a practical form for the use of the troops earlier than they actually did.

In the perfected form of the instrument that had been described by the Author, the advantages of chlorine over bleaching powder

were obvious, although it must not be forgotten that there was a distinct difference between the behaviour of liquid chlorine and bleaching powder. Chlorine was a more effective germicide apparently in the acid condition, while bleaching powder was an alkaline body. It was known that the efficiency of chlorine under those two conditions was different. Chlorine in acid acted as an oxidizing agent and thus destroyed organic matter, whilst bleaching powder, being alkaline, was not so energetic until the chlorine from it had been liberated by means of an acid. Therefore when bleaching powder was added to an alkaline water there was less germicidal activity than when chlorine was added to the water.

Liquid bromine had been also used as well as liquid chlorine for water sterilizing purposes. It was used in the "Eighties" or "Nineties" by the German Army. Their method was a very simple one. They had the liquid bromine in a glass bulb and broke the dose of bromine which was required for sterilizing purposes into the amount of water required. Therefore the use of a corrosive liquid like chlorine was worked out in that way in the case of bromine, before the bromine bleaching powder described by the Author was suggested for water sterilizing purposes. The relative activities of bromine, chlorine, and iodine were known. What was known as the Rideal-Walker coefficient of chlorine was 24, whilst that for bromine was 62, and for iodine it was about 100. Those figures were very roughly proportional to the atomic weights of the three halogens, and at the same time expressed their relative germicidal values, taking carbolic acid as the unit.

One of the most important points that had to be carefully considered when using any of these methods for sterilizing water was, as the Author remarked, the removal of the after-taste of the water. Whether bleaching powder was used or chlorine, there was always that effect, and various methods had been devised for destroying the taste. The Author had selected sulphur dioxide as a means of neutralizing that after-taste of the chlorine. That had to be carried about in a cylinder as a compressed gas and used with the addition of a regulator very similar to the doser used for chlorine itself, and care had to be taken to control the excess of the sulphurous acid

(Dr. Samuel Rideal.)
in order to ensure the destruction of the taste, and therefore it might be necessary to add something to remove the excess of sulphurous acid itself. Iron had also been used as a "dechlor," but amongst the things which he thought in practice were simple and useful, and which did not give any after-taste or add any injurious or additional substance to the water were hydrogen peroxide—which was simply water plus oxygen and, therefore, added nothing to the water—and permanganate. Potassium permanganate or sodium permanganate was a common enough reagent and had been used for pinking wells in India for the last fifty years, and had a very excellent effect in removing the after-taste of chlorine. It had been tried by Sir Alexander Houston in connexion with the London water supply with very satisfactory results. The permanganate when dissolved could be added to the chlorinated water regularly and simply, and it was very easy with that chemical to see that a sufficient quantity had been added, because one could note from the colour when an excess was present or not. He thought those were useful points to remember, and congratulated the Author in putting on record the details of the plant which they had seen that evening.

Major-General Sir William Liddell, K.C.M.G., said he could only say a few words as a user of the plant, and it might be of interest to state how the need for it arose. The authorities were faced with the problem in 1916 of providing water for a proposed force of about twenty divisions marching right through North-West Belgium. The water in that area, practically all from surface supplies, was probably as foul as could be found anywhere. It was extraordinary how bad the water supplies were, even in the big towns in that part of the country. It was necessary to provide for a rapid advance—which eventually, as a matter of fact, never took place. Thus we had, first of all, to depend on the water of the canals as the main sources of supply, although the water in them was grossly contaminated. The plant, or the early form of it, was therefore fixed on barges, which at the time was a novelty. Then motors had to be provided with the sterilizing plant to deal with water from surface wells and other sources remote from canals.

The capacity of the mobile sterilizing plant gradually evolved from 400 gallons to 1,200 gallons an hour by reason of the use of chlorine gas as a reagent. As the Author had said, there was an idea of providing a cavalry plant on horse-drawn vehicles as well; but this type was soon abandoned. That advance, as he said, never matured, but the mobile plants on barges and lorries proved extremely useful in every way on all parts of the Front. Their use was spread all through the Armies, and he thought that in many tight places the presence of water-sterilizing lorries had enabled the troops to maintain their positions and saved them from retirement.

Another point which he would like to mention was the forms in which the principles underlying the system of purification of water adopted in mobile plant was made use of for stationary plant. The River Yser was probably one of the most unpromising sources that could be imagined, or at least it was so in the neighbourhood of some of the intakes, but was the only large source available, and was made use of for the supply of a large section of the Front in 1917. A supply of between 200,000 to 300,000 gallons daily was required. At first a sand-filtration plant, which proved more or less a failure, was established, and was shortly succeeded by a system of sedimentation with alumino-ferric for about eight hours, in tanks holding about 50,000 gallons each, then by chlorination in tanks of similar dimensions by solution of bleaching powder added to the water as it was moved from one tank to another. That water was eventually pumped up 15 or 20 miles to the Front. It was a very simple method, and it required very careful watching by chemists, but proved thoroughly effective. The main interest in the system was that it dispensed practically with any filtration through sand at all.

Another form of the same simple type adopted in the later advance through Belgium in 1918 consisted of a small portable apparatus—really only two canvas tanks, each holding about 9,000 gallons, and a hand-pump or small motor-pump. One tank was a sedimentation tank, and in it the water was treated with alumino-ferric, being in contact with it for about eight hours.

(Major-General Sir William Liddell.)

The water was then pumped into the second tank and chlorinated as before with a bleaching-powder solution, and thence distributed to the troops. These small portable installations were in general use in Belgium towards the end of the War.

He (the speaker) thought it could be claimed that the water supply to the troops was extraordinarily good on the whole throughout the War. In the early stages of the War he thought he was right in saying that, whereas the French had something like 60,000 or 80,000 cases of enteric during the first eighteen months, the total British cases were something like 1,000. This comparative immunity was due to anti-typhoid inoculation being general, and to the careful treatment of the water supplied for drinking purposes.

Dr. Eric K. Rideal, M.B.E., F.I.C., said he was a chemist, but he had had a certain amount of experience with the various types of barges, not only of those described in the Paper, but also of the Bell system, which the War Office used in different parts of Belgium and France. He was practically the whole time in the Somme area, and did work both on the barges and on the portable water filters. There were always difficulties in dealing with water supplies during War time. First of all there was the usual type of difficulty which one sometimes got also in private work, namely, the question of people walking into the water supply. The French native troops, which came at different times into the area where he was situated, were rather attracted to the drinking water supplies for the purpose of washing. There were other difficulties, as, for instance, cohesion between the different parts of the troops—who was going to couple up the water supply to the pipe-line, and who was responsible for this, that, and the other. All those were naturally things that took place when some people were on a barge and other people were on land.

As far as the direct dosing with chlorine was concerned, there were two types of apparatus which could be used—the Wallace and Tiernan apparatus, which might be called the direct dosage, chlorine being passed straight into the water. Then there was the other

type in which a minor volume of water was chlorinated, and the minor volume of water thus chlorinated was added to the main bulk. The fundamental difficulty was the question of the measurement of chlorine, which was really a most heartrending problem to anybody who had tried to do it.

There were three types of apparatus by which one could measure chlorine—the Venturi type meter, the Pulsing type meter, and the electric-flow meter. The electric-flow meter had not yet been applied to the measurement of chlorine, but it had been applied very successfully to the measurement of other gases, and there was no reason at all why it should not be also used for the purpose of chlorine measurement. All those types suffered from the disadvantage that one was dealing with very small quantities of chlorine (usually less than one litre per minute), and therefore the measurement gear had to be extraordinarily accurate. The Venturi meter could be divided into two types—the pin-orifice meter, and the long capillary tube. They were extraordinarily sensitive to temperature changes and also sensitive to little bits of iron coming off the cylinders, flies and other insects, and things like that sticking in the very fine orifice. The quantity of chlorine passing through was very small, and therefore the orifice type of meter was not a very good one. The Pulsing meter was preferable, owing to the fact that there were no very small contractions or jets in the gas flow. The electric resistance one could probably be elaborated into a very serviceable mechanical arrangement.

After having divided the chlorine meters into types and obtained a measurement of the gas passing into the water, the question naturally arose to the mechanically minded; how could the quantity of chlorine left in the water after a certain time be measured? The usual method was to take some of the water and do a tritration. There were some very interesting facts which were electro-chemical in the action of chlorine on water. He got out the oxidation potential of chlorine in both acid and alkaline water, and it was 1·9 volts in acid water and 0·86 in alkaline water. That meant that chlorine was very much stronger as an oxidation agent in acid water than in alkaline

(Dr. Eric K. Rideal.)

water. Chlorine in acid solution was nearly as strong as potassium permanganate. What was called the hydrogen ion concentration of water was a very important thing, and had a distinct bearing on the question of adding gaseous chlorine in lieu of alkaline bleaching powder and alkaline hypochlorites. One really required to measure in a water, not the available chlorine, because that did not convey very much information, but rather the oxidizing potential of the chlorine. That was a problem Mr. Evans and he were interested in many years ago, and they provided a mechanical apparatus for measuring the oxidizing potential of chlorine in water. It was simply a piece of platinum wire in a copper tube. A little of the water was passed through that apparatus, which acted as a little battery, and it was quite possible by a very simple device to read off the quantity of water flowing. That would give the quantity of chlorine in the water as measured in the terms of its oxidizing power, and it differed very considerably from the very alkaline water of the London basin to the comparatively acid waters which were found in certain parts.

The rapidity of action of chlorine depended on its oxidation potential, which was the important feature. In France one was much struck with the need of some very rapid method of getting that oxidation potential, owing to the fact that the water was always varying in chlorine absorption, and tests were frequently needed with potassium iodine starch, in order to see that the water was not ultimately going to kill everybody about the place. A little mechanical device was rigged up for adding the potassium iodide in starch. It took the form of a tube and siphon, and if the colour remained blue, one might be quite happy that things were going right, but the electrical method of measuring the quantity of chlorine was preferable to that.

The amount of chlorine with different waters was remarkably varied. On the Somme they had a great opportunity of studying the action of chlorine on impure water, which in the autumn season was polluted with a great deal of vegetable matter, and in the summer and other times with animal pollutions as well. The action of chlorine on vegetable and animal pollution was very

different. The after-taste was extraordinary in animal pollution, and much less in vegetable pollution. The chlorine absorption was much higher with vegetable than with animal pollution. It was not quite clear what the peculiar taste was due to, but he thought it might be the presence of phenoloid bodies in the animal refuse, and of course a very small quantity of chlorphenol in the water would cause an extraordinary taste. The action of chlorine on micro-organisms was also most interesting; in fact, one type of B. coli could be changed into another in a short time by treatment with traces of chlorine. It all arose really out of the method which had been in use in the States for many years, and had been and still was being investigated in this country from all those different points of view.

Mr. William Paterson said that most engineers would share with him a certain feeling of diffidence in entering into a discussion on the subject of the sterilization of water supplies, for they felt that it was to the chemist and bacteriologist that they owed their knowledge of the action of the reagent. The Paper gave little scope for discussion, as it described only one particular type of apparatus used during the War, and therefore was not a subject upon which one would care to enter into a critical discussion, but the Author had referred in his general remarks to one or two points that he thought called for a reply. The general impression conveyed by the Paper was that the process of chlorination was first developed in America, and to some extent that was so, but he would have been better pleased had the Author referred to the first instance in which chlorine was used for the disinfection of water supplies, as at Lincoln in 1905.

On the first page the Author stated that "bleaching powder or chlorine was first used to sterilize the supply of drinking water in 1897 at Maidstone, where an epidemic of typhoid was raging." That was hardly the case. On that occasion hypochlorite of lime was used simply for flushing out the mains and ensuring their disinfection. The polluted source of supply was then cut off. Prof. Sims Woodhead was responsible for the good work done at

(Mr. William Paterson.)

Maidstone, and in his Paper on "Results of Sterilization Experiments on the Cambridge Water," read before the Cambridge Philosophical Society in 1910, he said: "I filled the whole of the water mains from the gravitation reservoir with 1 in 300 solution of chloride of lime or bleaching powder. From the complaints received by the water company from all sources I was satisfied that we had attained our object." It would be noted this was simply disinfection of the mains and not sterilization of the water supply.

No Paper on the chlorination of water supplies was complete without reference to the classic researches of Dr. Houston and Dr. McGowan, who in 1905, for the first time in history, maintained the sterilization of a polluted supply to 50,000 people. A full account of this work was given in the Fifth Report of the Royal Commission on Sewage Disposal, and he would strongly advise anybody interested in the subject to secure that Report. Their researches determined :—

(1) The amount of chlorine absorbed by waters of varying purity.
(2) The effect of sunlight on the action of chlorine-sterilized water.
(3) The effect of chlorinated water on slow sand-filter beds.
(4) Factors affecting taste troubles, etc.

It had been an invaluable guide since 1905 on all matters relating to the sterilization of water supplies with chlorine.

With regard to the question of the sterilization of water by chlorine gas, he regretted the Author made no reference at all to the first occasion when it was suggested that gaseous chlorine should be used for the sterilization of water supply. The idea did not originate in America, but came from Lieut. V. B. Nesfield, a British Officer in the Indian Medical Service. He (the speaker) had with him a copy of *Public Health* for July 1903, containing Nesfield's Paper on "A Chemical Method of Sterilizing Water without affecting its Potability," advocating the use of portable gaseous chlorine plants and dechlorinating with sodium sulphite, and giving the result of actual tests carried out with these reagents. Surely the Author might have made some reference to that first occasion on which it was suggested that gaseous chlorine be used,

as a simple portable means for sterilizing water supplies for troops. This process was nine years later brought into practical working in America by Darnell and Ornstein. In his opinion Ornstein's 1913 patent indicated the first really practical method of applying chlorine gas for water-sterilization purposes. Although filed only a year after Darnell's, it represented a marked advance in the mechanical development of the process.

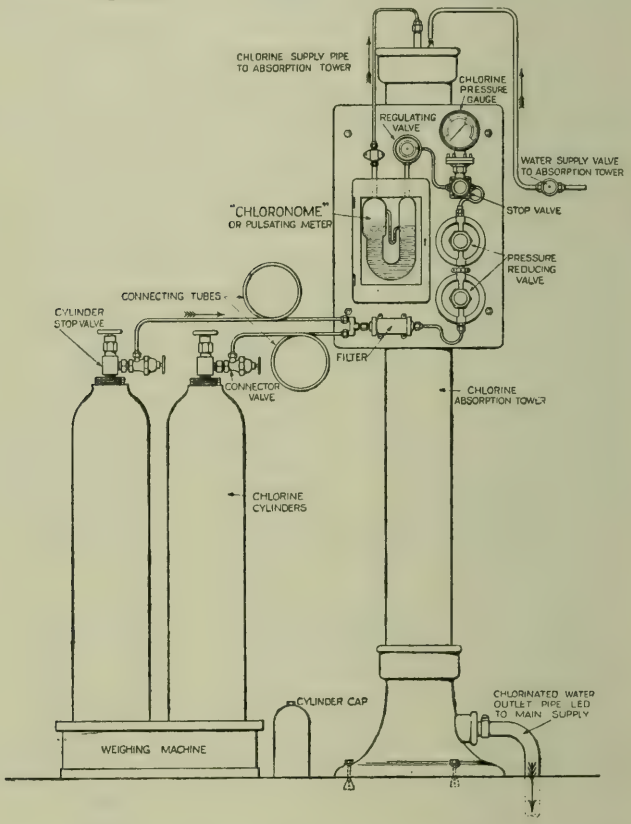
The Author stated that there was less taste with gaseous chlorine than with hypochlorite of lime, but the speaker's own experience had not led him to think so. He believed water accurately dosed with hypochlorite was no more liable to taste troubles than that treated with gaseous chlorine, and he understood others had a similar experience. The advantage of gaseous chlorine was the possibility of adding it more precisely than hypochlorite of lime. Taste, due to excess of free chlorine, could be removed by dechlorinating, but if the taste was due to the reaction of the chlorine with impurities in the water, no dechlorination would remove it. Sir Alexander Houston, in his Thirteenth Research Report for the Metropolitan Water Board, stated on page 37 :— " When, however, a chlorinated water has developed the ' iodoform ' taste, dechlorination is powerless to remove it." According to that authority the " iodoform " taste could be removed either by increasing the dose of chlorine sufficiently or by adding potassium permanganate, as well as chlorine, to the water.

The Author had referred to the active corrosion that was set up when water was brought into contact with chlorine. That was undoubtedly one of the greatest difficulties to be overcome in chlorinating plants. At the invitation of the President, he had brought an apparatus devised to overcome that difficulty, which he exhibited and explained, Fig. 17 (page 1164), pointing out the special feature that the instrument with its valves and mechanism was completely isolated from the water by a column of liquid unaffected by the gas or water, so that by no possibility could the moisture get into the mechanism and cause corrosion. The reducing valves maintained a constant pressure of 10 lb. per square inch on the regulating valve. This was adjusted so as to give the required flow

of gas to effect the sterilization of the main supply under treatment. The rate of flow was indicated by the rate of pulsation of the sealing liquid in the U-tube meter. The plant demonstrated could treat

FIG. 17.

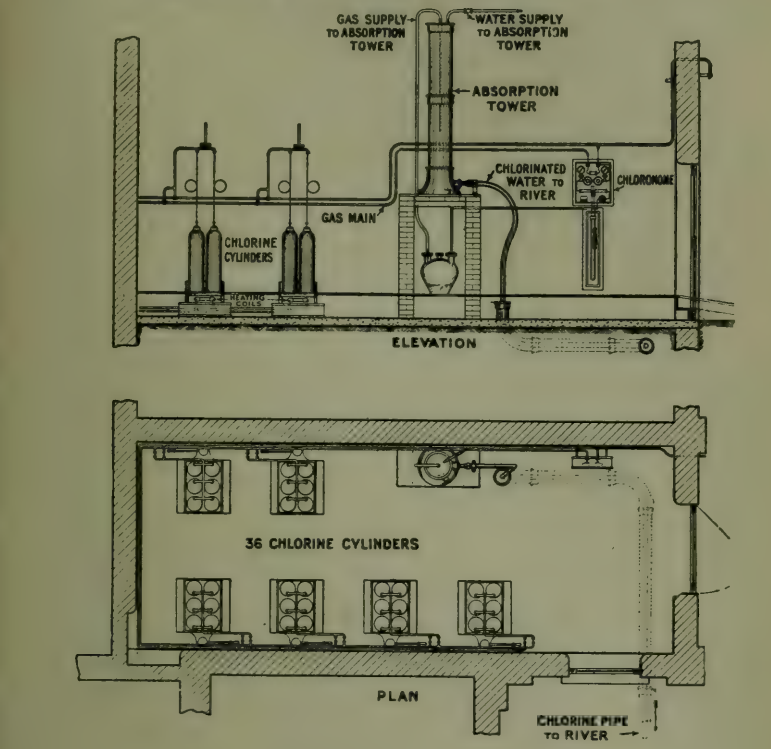
"Chloronome" for Sterilizing Water by the Addition of Gaseous Chlorine. Capacity 10 lb. of Chlorine per day. (Paterson.)



from 5,000 to 100,000 gallons of water per hour, and could be set at will to pulse at any speed from one in 6 seconds to one in 300 seconds, giving from 0·5 to 0·01 lb. of chlorine per hour. When once set, the precise rate of pulsation was maintained continuously.

FIG. 18.

Arrangement of Gaseous Chlorine Plant, Sterilizing New River Water. Capacity 400 lb. of Chlorine per day. (Paterson.)



(Mr. William Paterson.)

Fig. 18 illustrated a Chlorinating Plant of 40,000,000 gallons daily capacity which he had installed for the Metropolitan Water Board to treat the New River water supply. The apparatus was fitted in an existing storeroom where thirty-six cylinders mounted on six weighing-machines were connected to the regulating meter and board. The measured gas entered near the base of the elevated absorption tower, where it was absorbed by a minor stream of water which gravitated through a distributing pipe led across the New River. The distributing pipe was fitted with a large number of vulcanite nozzles which ensured the uniform distribution of the chlorinated water throughout the width of the stream. The capacity of this apparatus was 400 lb. of chlorine per day.

Mr. V. Hjort thought the Paper might have been entitled "The Sterilization of Water by Chlorine Gas for Military Purposes." The Author had had considerable experience, and a longer experience than most people associated with military work, in the handling of portable plant for use by the troops, and it was evident that he had concentrated more on that part of the work than on the general sterilization of water as, for instance, for municipal purposes. It was evident that both types of apparatus were found useful for the two classes of work, namely, stationary work and portable work. Probably the reason why the Americans did not bring over the type of chlorinating plant for the use of chlorine gas was that it was felt that the problem of designing a small portable unit, which was more wanted than any other type of plant for the troops in case of an advance, had never been tackled.

He would like to give a short historical explanation of the development of the portable sterilizing plant and show the early attempts which were made to solve the very difficult problem, as that would enable the members to understand that the War Office had a problem that was not easily solved, as it had not been attempted before. There was a certain amount of humour attached to the installation shown in Fig. 19, Plate 24. In 1914, experiments were carried out in the City of Paris on the treatment of water by bleaching powder, and a certain treatment for cancelling

the excess chlorine; and on the basis of those experiments the little equipment shown was placed on a hired furniture removal lorry, as no lorry could be obtained from the War Office, and was shown to the War Office in 1915. The whole thing was a very temporary affair. Hand pumping was resorted to, and only a small output of 80 gallons an hour obtained, quite out of proportion to the enormous cost of the lorry and the cost of running it, but at any rate it was the first attempt in the right direction.

The next attempt was illustrated by the Author in the Paper. Two plants arranged on general service wagons were constructed, but they were never sent to the Front, as, whilst they were being designed, further experiments were carried out, and it was found that a much greater capacity could be obtained on a practically similar area. Fig. 20, Plate 24, showed what was brought out then, consisting of sterilizing plant using bleaching powder and with iron sulphate for dealing with the excess chlorine. The unit on the left of the illustration was designed for the urgent purpose, as called for by headquarters, of dealing with metallic poisoning which was reported to have taken place at a certain point on the Front, and instructions were given for experiments to be carried out. They were difficult experiments, because the passing of metallic poisoning by means of water had never been thought of. The matter was so pressing that the type of plant shown was developed, and it was so designed that it could be either used for sterilizing or used for taking poison out of the water. The officer in charge, who was in charge of the very earliest type of apparatus, was present that evening, Captain R. W. Stickings.

The next type of plant that was got out was the plant utilizing chlorine gas. Not only was it possible much more quickly to sterilize water, but it could be produced at a much higher rate. A 3-ton lorry, which up to then had been only capable of supplying water at 400 gallons an hour, was turned into a working unit of 1,200 gallons capacity, and, as a matter of fact, it was on record that that plant had been worked up to 2,500 gallons for 22 hours consecutively at a time when water was very urgently needed. So that it would be seen that progress was made not only in research but in output.

(Mr. V. Hjort.)

Fig. 21, Plate 24, showed the first chlorine-gas apparatus brought over from America. It was mounted temporarily, with the requisite pump, engine, filter and contact tank, on a lorry lent by the War Office for the purpose of the experiment, and this was returned as soon as the experiment was over. The whole of that equipment was got out in a hurry to put to a practical test the chlorine-gas apparatus, and to ascertain what contact was necessary in order to secure sterilization of the water. That was the first of the type ever made, and when compared with Fig. 11, Plate 22, it would be seen that, except for details of piping, these designs were identical. In due course the construction of plant for India and for the Italian and Belgian Fronts followed, and there was a development from 125 gallons an hour to 2,500 gallons. The efficiency of the plants had been officially acknowledged, and it might interest the members to know that it was on record that perfectly sterile and good water had been produced in seven minutes after the taking of a German trench. It could be imagined what that meant where water was practically as valuable in the case of an advance as ammunition and food. It was established that one big move would have been impossible without the use of quick methods of dealing with very bad water, and that was safely secured. It was a matter of satisfaction, he thought, that this country led the way and produced the first type of plant which was afterwards used by the Allies. The Americans, when they came over, brought an outfit very similar to the one that had been shown, except that they resorted to the older method of dechlorination by sodium hyposulphite.

As the Paper had been written mainly to deal with water treated for military purposes, he had not included in his notes anything dealing with the municipal water service, but in that connexion America was a long way ahead of any other country in the chlorination of water, and particularly so in the use of chlorine gas. The whole of the supply of greater New York was safeguarded by the installation of gas chlorinating apparatus at all possible points. The largest one was dealing with 500,000,000 gallons a day, where previously bleaching powder had been used, but as soon as the gas sterilizing apparatus was perfected, it was changed over.

Captain R. W. E. Stickings, O.B.E., said he was sorry that the chemists seemed to have monopolized the Meeting, because he had to plead guilty to being a chemist himself. As Mr. Hjort had said, he went to Brentford in the early days when the portable sterilizing lorries were in their infancy, and he mobilized the first unit and took it out to France. That unit was in working condition up to the time of the Armistice. During that time his company comprised thirty special lorries, some of which were for depoisoning water, and others for sterilizing purposes. The depoisoners had never been used as such, but were used as sterilizers. Altogether nearly 60,000,000 gallons of sterilized water was delivered to the troops by No. 1 Water-Tank Company (above). Various letters of congratulation were received from the staff officers of the Fourth Army in particular, with whom the detachment was working for most of the time. On one occasion they managed to get one of the sterilizers into position delivering water within 24 hours of the occupation of a village, during the 1918 advance. The weight of the lorries on the road was about 8 or 9 tons, and in a road that had been blown to pieces by shells and mines this was rather a difficult proposition to undertake. Those who had had lorries ditched knew how other people on the road regarded them.

He thought perhaps the introduction of the chlorine gas tended towards centralizing the Army water supplies. The cost of one of the compensators was a very big item when only dealing with small supplies, and the water engineers endeavoured to centralize the supplies as much as possible, so that a chlorine-gas chlorinator might be used to advantage. The water engineers and the water-tank companies worked together very well indeed; they were under the control of the Royal Engineers and received all their details from them. One of the things they tried to do was to chlorinate water at the source. Naturally that was an idea that would come into anybody's mind, namely, that if the supplies had to be centralized, the chlorination should be done at the source and the sterilized water distributed by the pipe-line system, and in that way the number of chlorinators required would be minimized. It was found in practice that this was a very difficult thing indeed

(Capt. R. W. E. Stickings.)
in the field, because when there were 10 or 12 miles of pipe-line, it was not easy to keep the water sterile. He had once put in thirty parts per million of chlorine at a source, which made the water perfectly horrible, and on going to the end of the pipe-line, 3 miles away, and waiting for three days he found that no chlorine got through, and the effluent was not sterile ; all the chlorine had been absorbed in the inside of the pipes.

The French had a chlorinating system somewhat different from the British, but it was very simple and satisfactory indeed, and personally he used it on a few stationary plants in France. They sterilized their water by means of *Eau de Jovel*, which was sodium hypochlorite. In making up solutions of ordinary "chloride of lime," the difficulty was that there was a tremendous excess of lime, which would not go into solution. On the other hand, *Eau de Jovel* was a perfectly clear liquid, was supplied commercially in France, and could be bought in shops as a sterilizing agent by civilians, so that a large supply of the solution could be commandeered. The water was simply pumped through a main, from which there was a by-pass which took off a little of the water through a sort of water-suction pump; this sucked in from the strong solution a certain amount (which amount could be regulated by means of a tap), and the movement of the water through the main brought the chlorinated by-pass water back again into the pipe, where it mixed with and sterilized the water in the mains. The French had those systems erected practically all over their Army area. He had come in contact with the French chemists in charge of the water supplies, and he thought their system was very excellent, but they had to deal with people who did not really care what they drank, and consequently did not care what they drank it from. That was one of the difficulties the British Company had to encounter. After they had chlorinated the water, the most urgent problem was how to keep it sterile until it was consumed. In order to do that, as far back as 1916 they dispensed with any idea of dechlorinating water ; as a matter of fact, it was detrimental to do so. Unless one-half to three-quarters of the chlorine was left in the water, by the time it reached the people who were going

to drink it, it was no longer sterile; consequently there was no dechlorination at all on the old type of plant.

Mr. William H. Patchell (Member of Council) said several weeks ago, after travelling all night, he got out of the train in Detroit and took a bath, when he was forcibly reminded of the years gone by when he used to make skeleton leaves! He thought the room had been cleaned out with chloride of lime, but was told that they were chlorinating the water. Bearing in mind that the present Paper was to be read at the Institution, he tried to get particulars in Detroit of what they were doing. He met Mr Theodore Leisen, the engineer of the waterworks, who very kindly showed him the plant which had been used for chlorinating with gas there since 1915. The apparatus was not one of the automatic machines that had been shown by the Author, but was by Wallace and Tiernan, manually operated. The chlorine cylinders were put on large weighing machines, and the chlorine was bubbled into water at a steady pressure of 10 lb., which was run into the inflow of a large settling tank. The pumps drew the water from the far side of that settling tank and delivered it into the town mains. There were some 1,500 miles of mains, 65 miles of which were from 42 inches to 48 inches in diameter, so that there was a good chance of any sort of slight error averaging out. He did not go to the works until he had been in Detroit for ten days, and by that time he had quite lost any sense of taste or smell of the chlorine in the water. He asked the engineer if he had altered the quantity of the chlorine put into the water, and he said they had not, that they kept it quite steady. The death-rate in Detroit was low and would be lower still if it were not for the motor cars! The quantity of water handled in Detroit was 150,000,000 gallons a day, which was 150 gallons per head of the population, a higher figure than our average. That was probably due to prohibition!

He was in another waterworks, which were constructed for 750,000 gallons per day, where they were handling 13,000,000. The water was kept free from taint by chlorine gas. The water in both cases was taken from the Detroit River. It was

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more or less muddy, so they were at present arranging in Detroit to put down filter-tanks. At present they had none; they had merely the large settling tank. It was also interesting to note, in connexion with the Detroit Works, that they had laid wooden water-pipes within the last hundred years. He had dug up several wooden pipes in the Charing Cross area, but he did not think any had been laid in London for something like two hundred years. In New York he was spending a Sunday afternoon with a friend, a great admirer of Leonardo da Vinci, looking over volumes of drawings by that wonderful man, and amongst them he discovered a machine for boring out wooden water-pipes!

In justice to what had been said with regard to the Americans that evening, he had asked Mr. Leisen for a copy of Wallace and Tiernan's catalogue, from which perhaps he might be allowed to read a paragraph: "Notable among the first large-scale attempts to sterilize water by the process of chlorination is that undertaken under the direction of Dr. A. C. Houston (Fifth Report of Royal Commission on Sewage Disposal, Appendix IV), Director of Water Examinations of the Metropolitan Water Board of London, England, in 1905. At that time sodium hypochlorite was applied to the Lincoln (England) water supply, with gratifying results." This showed that even if the Author in his short note had not quite meted out even justice between the American and the Englishman, the Americans themselves had done so.

Mr. Thomas Bouts asked whether the Author could tell him how it was known that the water was sufficiently sterilized, and how much chlorine was required to sterilize a given amount of water.

Mr. A. W. Marshall said he would like to know what was meant by metallic poisoning. Was it derived from pipes or fittings?

Mr. W. J. A. Butterfield said a good deal had been heard about the sterilization of the water supply in France but very little about that in other spheres of the War, such as the Far East, where

sterilization by chlorination did not get properly to work until the War was fairly well advanced. Up to within a few weeks of the fall of Kut it was altogether inadequate, and the large number of deaths from water-borne disease were due to the chlorination of the water supply not being carried out properly. During the War an officer in a line regiment happened to arrive at Basra in charge of men going up with the Relief of Kut expedition. He was seized upon by the medical officer, who happened to know him as an old schoolfellow who had become a trained chemist, and was forthwith put in charge of the sterilization of the water supply at Basra. He reported in a private letter that up to that time it had been entirely in the hands of Indian natives, and either it had been obviously inadequate or the water had been rendered undrinkable. He set to work with a barrel as an improvised churn, using chloride of lime, which was available; and a short time afterwards he used chlorine driven off from the chloride of lime by the addition of acid. He made up a solution of strong chlorinated water, which was standardized and then put into bottles and sent up by the river steamers, with instructions that one bottle would sterilize so many gallons of river water, the proportion varying according to the season of the year. Once that system got fairly to work there was no water-borne disease in that area. Later the improvised plant was improved upon. The account of the matter should be obtained direct from Captain Frank L. Bassett, B.Sc., F.I.C., who carried out the work, and who was now the chief chemist to the civil administration of Mesopotamia and had his quarters in Baghdad.

The Author had referred to brominated water. It would be undesirable to rely on bromine in future wars, unless we were sure that Germany would be neutral or on our side, because almost the only sources of bromine and bromine compounds in the world were in German territory.

Lieut-Col. A. E. Davidson, D.S.O., R.E. (Member of Council), said his experience with the types of plant, referred to in the Paper, had been confined to dealing with those patterns carried on motor-lorries in France. During the War there seemed to be an idea that,

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if there were any awkward looking object lying about at home, the first thing to do was to fit it up for mechanical transport. There were four companies dealing with the purification of water. The two early companies had bleaching-powder sets, and the two later companies chlorine-gas sets; and the latter were an enormous advance in increasing the output per set from 400 to 1,200 gallons per hour. As an indication of the saving effected, there were at one time on order from England four complete M.T. companies, and two of them were cancelled simply owing to the increase in the capacity. In fact, the capacity of the new plants was almost a drawback, because some of the places where they were required had a relatively small output, and it seemed rather a waste to use a 1,200-gallon plant to deal with a small supply.

The only other objection from the mechanical transport point of view was the excessive weight for the lorry. It was not only the weight, but the arrangement. Some of the very heavy parts came behind the back axle. He was glad to see that a lighter type had been evolved, which really made the plant much more portable for use with the Army, namely, the one described in Fig. 9 (page 1139). A number of the lorries carrying bleaching-powder sets were altered in France to chlorine-gas sets, and the people at the base workshops were continually sending urgent messages that it was very bad luck on the lorry to load it up to such an extent.

Captain J. Stanley Arthur, in reply, said that, with regard to Dr. Samuel Rideal's questions, he would like to point out that sulphur-dioxide dechlorination was not quite as Dr. Rideal had put it. In the Army, chlorine was always left in, for the purpose of being sure that the water was sterile, and therefore it was utterly unnecessary to add an excess of sulphur dioxide to remove all the chlorine. By an extremely simple chemical test, the amount of chlorine remaining could be determined accurately to 0·1 of a part per million parts of water, in less than half a minute. He did not think General Sir William Liddell's remarks needed any reply.

With regard to Dr. Eric Rideal's remarks as to the Venturi meter giving a considerable amount of trouble, from actual experience

he thought the only trouble that had arisen in that work had been the small glass Venturi orifice. That trouble was expected, but it was not due to dirt, but to some curious condensation on the glass which could be removed quite easily by carbon tetrachloride, or even better by alcohol. Every lorry leaving for France was equipped with a spare orifice and a corresponding spare scale, and he thought that a man who had had any experience with those could exchange them in two or three minutes if necessary, without taking very great precautions. He wished also to point out that the plants were designed for active service, and it was not an easy matter to manipulate delicate electrical instruments in warfare. He was quite aware that it was easy to do such things with accuracy when there was a fixed definite point from which to work.

Mr. Paterson had accused him, and justly, he thought, of not dealing quite fairly with the chlorine question. He had to own frankly that he was in a very difficult position when he was asked to write the Paper; he thought he might say that he almost refused to do it because it was quite unfair to other people engaged in the work. He himself did not come into the work until early in 1916, and other people had done a great deal of work before then. He came into it as a chemist and as an amateur engineer. He claimed nothing beyond the chemical side of it and the adaptation of his chemistry to engineering methods. With regard to the Paper itself, he had the difficult task of writing a chemical and bacteriological Paper for The Institution of Mechanical Engineers—not an enviable task—and he only hoped that his drawings, such as they were, would meet with approval. He had to make the Paper as short as possible. It was more or less a War Office matter, and it was written about twelve months ago and had been delayed ever since, partly because he was leaving the country.

He thought that, as a chemist, he might say that the water supply of Maidstone was really sterilized. When he said that it required, for the dirty canal water on which they had to work, an average of three parts per million of chlorine to sterilize it, he thought it would be agreed that there had been enough left in the pipes to sterilize that water for some time. With due regard to the English

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work on the subject, he thought the Americans were considerably ahead of us; they had been doing the work for a long time, and were compelled to do it in the first place, because they had to draw their water from sources which were always polluted. That he believed was the explanation of the speed with which they got to work on the problem. At the time when he started work on the subject, there was no other chlorinator in existence which would do what was required. The chlorinator devised by Messrs. Wallace and Tiernan proved satisfactory, as had already been stated.

The problem in connexion with the taste of the water was a very curious one. General Sir William Liddell would remember that he (the speaker), when demonstrating the first machine at Abbeville, noticed a most objectionable taste in the water under treatment; it was like iodoform. At first it could not be traced, and he had the most wonderful theories with regard to the formation of substances having an iodoform taste by the reaction of chlorine with organic matter which was present, but he traced it next day and found it was due to the fact that they were washing ambulances a little higher up from his intake. He need hardly say that some of his theories were no longer tenable. But there was that possibility, and he had found that where the water had been extremely bad to work upon, where it was stagnant or sewage or very foul, it was not possible to get rid of the whole of the taste, but if one worked on water such as that of the Thames at Richmond, he was prepared to say that there was no taste in the water if sterilization was carried out properly, and the chlorine was removed by means of sulphur dioxide.

Mr. Hjort had put the question very plainly. Mr. Hjort was associated with the contractors who carried out the whole of the portable work for the War Office, and also carried out some of the other plant, stationary and on barges. Mr. Hjort placed at the disposal of the War Office a station, and the War Office worked in conjunction with his firm, suggestions being made by various officers and by the firm, and immediately carried out. The chlorinating tests were first of all carried out actually on a plant which was composed of a few old tanks and an old engine, and

results were obtained from that, and he had put some of them in the Paper. It was then suggested that the plant was capable of being mounted on a lorry, and that was done and the War Office inspected it. He thought they were very frightened of chlorine gas; at all events, his instructions were to watch results very carefully. He did so, and in talking with General Sir William Horrocks on the subject, he suggested that it would be quite possible to increase the size of the plant without adding too much weight to the lorry, and he told him he thought it was quite possible to do that on the spot. It was done by three men, two Army Service Corps men and one R.A.M.C. man, and himself, and the whole thing was constructed on a lorry upon which a sterilization plant had been constructed, but which was not suited for field use. A new engine and pump were used and supplied by The United Water Softeners, Ltd., and it differed very much from the plant illustrated. Considerable hesitation was shown at the use of chlorine gas, and before he was allowed to start the work he was told he must be able to use bleaching-powder solution, and must be able to dechlorinate, not with sulphur-dioxide gas only, but also with sodium bisulphite solution. For some time he had been trying to inject bleaching-powder solution and sodium bisulphite solution into water under pressure and to measure the amount injected. It was not an easy problem. It was the first of what was called the pressure type. There were earlier types which were failures.

The plant that went to France differed in the respect that it was fitted for sterilization by chlorine gas and for dechlorination by sulphur dioxide gas, and at the same time sterilization by bleaching powder and dechlorination by sodium bisulphite, if it was required at any time. The plant was taken to France, and in less than a week the whole of the bleaching-powder and bisulphite solution apparatus was scrapped. He wished also to point out that the original plant built by The United Water Softeners Co. had on it two of those elaborate instruments he had shown, which cost considerably over £200. It seemed utterly unnecessary to add sulphur dioxide so accurately by one of those instruments, when it could be done by a simple hit-and-miss method which was under complete

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control, and so the hit-and-miss method was adopted. It was done by a pressure-gauge and a back-pressure valve—later on a simple arrangement on the principle of a bicycle valve was used—and the sulphur dioxide was added by the rotation of the needle-valve, made by the British Oxygen Co. That had remained standard right through and was the standard to-day, and the total cost of it was very small indeed in comparison with a chlorinator. His original apparatus was improved upon by expert draughtsmen and designers, but the weight remained the same; in fact, it was slightly increased. The weight was mentioned as 8 tons, but it was really 8 tons 4 or 5 cwt., including a great deal of stores. The only reply he could make to Captain Stickings (page 1169) was to say that he (Captain Stickings) was the first chemist to start on the work.

With regard to metallic poisoning, it was referred to by chemists as poisoning which might be due to the presence of any metallic salt—copper sulphate, mercury chloride, potassium cyanide, arsenic compounds, or any chemical which could be dissolved in water and so render the water poisonous. Before he came into the work, it was part of the problem considered by Professor H. B. Baker and Sir William Horrocks, and machines were made to remove the whole of the poison and render the water perfectly fit to drink. It was expected that the Germans would put poison into the water, and that it would not come from the pipes.

With regard to the supply in the East, on his return from France, he was engaged in work as a research chemist and chemical engineer, and apparatus was designed for the East, but he could not say what was sent out.

Colonel Davidson had spoken of the size of the lorries (page 1174). The idea of increasing the size so much was to save transport and troops. For the India Office the weight and size had been reduced practically 50 per cent, and the output only reduced from 1,200 to 1,000 gallons an hour.

Discussion in Manchester, Thursday, 25th November 1920.

The CHAIRMAN (Mr. H. P. HILL), in opening the proceedings, said the members would find that, in the Paper, Captain Arthur gave a very interesting account of the way in which the water supplied to the troops during the war was sterilized, so that the health of all concerned was well maintained. Of course it was a truism to say so, but he did not suppose there had been any war in the history of mankind in which there was less mortality due to the diseases which arose from hygienic causes as distinct from fighting. The sterilization of water was one of the most important causes contributing to that result. But the interest of the subject did not lie entirely in the application of this process of sterilization by chlorine gas to water supplied to troops on active service; it also applied to the water consumed by the ordinary civilian population. Not every town nor every country was in so fortunate a position, with regard to water supply, as Manchester and this country as a whole were in. At many places in other countries, the supply was derived from sources which, if not absolutely polluted, were, at any rate, of so questionable a character that filtration did not entirely "fill the bill" in preserving the health of the inhabitants. For instance, it was well known that in America, such diseases as typhoid had in times past been more or less endemic, and it was said to be largely due to the water supplied. There was no doubt that the introduction of this process of sterilization by chlorine gas added a safeguard to the processes of filtration, whether they were chemical or whether they were merely by gravity beds. Where only water of unsatisfactory character was available, such treatment was bound to have a great effect upon the health of the people, and the results would be reflected in statistics as time went on.

He did not know whether Captain Arthur would be able to tell them the places in this country where the method had been adopted. He knew that it had been applied to the Thames supply of London, but to what extent he could not say. However, he believed it had been found very useful there during the War. Rotherham

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had installed it, but whether it had been actually brought into use he could not say. The system had possibilities; what the scope of those possibilities was, remained to be seen. It might have the effect of destroying vegetable organisms in water to such an extent as materially to reduce the deteriorating effect which some waters had on the pipes through which they were delivered to the inhabitants. If so, it could not help being valuable. But all this at present lay on the "knees of the gods." He mentioned these points to indicate the possible field that lay before this process, and to interest the members in it.

Captain ARTHUR then presented his Paper in abstract.

The CHAIRMAN said they had listened to a very instructive and interesting Paper on a subject which he did not think the members came into touch with very much in the ordinary course of events. If one wanted to sum up what the Author had told them in regard to research, it might be done by writing down the maxim, "Necessity is the Mother of Invention." Certainly, if the necessity had not been there, Captain Arthur would not have been able to tell them of the developments which had taken place and the progress which had been made in dealing with the emergency supply (should he call it) of large bodies of mobile troops. Of course, the Author had given them the point of view of the authors of the invention; perhaps some members present could give the other side by saying what they thought of the effluent that was turned out. He had heard it said that chlorinated water was not exactly an attractive kind of luxury. At least, the men at the Front did not seem to have always regarded it as such; they appreciated that it was the best that General Head-Quarters could give them, but that did not make it any the more palatable. If, therefore, anyone in civil life was thinking of applying chlorine to the sterilization of water, perhaps the Committee before whom the proposition came might not give it that cordial reception for which the promoter might hope, especially if that Committee included ex-service members.

He happened to be in Lincoln professionally about the time of the typhoid epidemic, and he remembered that chlorine was rather prevalent in the liquid they had to use in washing. But he thought that so far as the population of this country was concerned, they were happily circumstanced in matters of water supply. They were not driven to the expedients that the people in other countries were forced to use. Englishmen did not always appreciate the advantages that they enjoyed on that account; they were apt to grumble because some dirty water came out of a tap, but if they went across the Channel—to go no further—they might still meet with samples which would make them wish they were back home again.

The question of the treatment of water with chlorine in this country might occasionally arise, but he doubted whether it would do so often. Nevertheless, the Paper to which they had listened that evening could not but be instructive, and it would materially spur the imagination of those who had to deal with questions of this kind in foreign countries.

Mr. R. Forsyth asked whether it would not be advisable to use ozone, which was now obtainable in quantities sufficient to meet such a need as was dealt with in this case. If any peculiar advantage resulted from the use of chlorine, he would be glad to hear of it.

Mr. Ernest Reuss asked how, in the case of public services, the apparatus would be adjusted for the supply of chlorine, in sterilizing the water in the mains where the pressure varied from hour to hour.

Mr. C. Bentham said he would like to know whether, in making the experiments leading up to the perfecting of the plant, Captain Arthur always used pure chlorine gas, or did he attempt to mix chlorine gas with air or any other inert gas, so as to get a better mixture during the process?

Mr. T. Roland Wollaston said he had had a good deal of experience of dealing with water for industrial purposes, though not for drinking, and consequently, with the volumetric regulation of chemicals. He had never had to deal with reagents in a gaseous state, but had dealt with the measurement of small volumes of gas in other connexions, and knew the extreme difficulty of obtaining consistency and accuracy. He understood the Author to say that he obtained chlorine liquefied under pressure. It was obviously easier to measure a liquid than a gas. Would it not be possible to measure the chlorine volumetrically, while under pressure and in liquid condition, letting it be admitted as a gas afterwards? It appeared to him the mechanical difficulties in doing this would not be very great.

The Chairman said there was one point he would like the Author to deal with. They knew that the process was applied in an emergency, and questions of cost were not raised or considered. Now that they had returned to more peaceful times, he wondered whether the Author could give them approximately—he did not ask for an estimate—what the cost would be, say, per thousand gallons of water chlorinated by apparatus of this type, though not necessarily restricted to a travelling installation.

Mr. C. Bentham said he wished to put another question. Would the Author give them an idea of the relative weight between the gas used and the water treated? Was it dependent upon the amount of foreign matter in the water, or was it simply a fixed proportion between the weight of the water and the weight of the gas?

Mr. Daniel Adamson (Member of Council) said the Author might have mentioned another method by which chlorine could be applied to water; it was based upon an original patent taken out by Watt. The principle was one in which electric current was passed through salt water and so formed an electrolytic compound of chlorine (sodium hypochlorite) which had sterilizing effects and

was also very useful for bleaching purposes. It was used in laundries, for example, with very satisfactory results. Where it interested them this evening was the direction in which his own firm were now using it—for the reduction of weeds in mill ponds and tanks connected with works. Weeds were a very troublesome factor in ponds used for condensing purposes, and caused a considerable amount of trouble and expense to the owner. His firm had a small plant working for that particular purpose, and he had brought to the Meeting a small sample which showed the effect of this electrolytic method upon the weed growing in the tank. It had been taken from the filters on the way of the water from the tank to the works, and was apparently the killed weed which, at this time of the year, grew very freely and necessitated a clearing of the tank, certainly once a year, to enable them to carry on. The advantage of this process for their purpose was that as users of electric power they were able to provide their own bleaching or sterilizing agent without the use of chloride of lime or chlorine, which were chemical compounds and would have to be purchased elsewhere. All that they had to purchase, apart from electric power, was the salt, which was not used in very great quantities, one ton worth about £4 lasting a year, during which time about 8 million gallons would be treated. They avoided the difficulties of using chloride of lime which was dirty, and unreliable unless under constant supervision, and the dangers of using chlorine gas; and the whole method lent itself to supervision by workmen of less skill than the Author had explained had to be brought to bear upon the apparatus described in the Paper. The electrolytic method was more easily controlled, much safer, and left no objectionable taste.

Captain J. Stanley Arthur said ozone had been used as a sterilizing chemical for a considerable time and with a good deal of success. There was an installation working to-day in France. The greatest drawback to its commercial use was that it imparted a taste to the water which was most difficult to remove; he believed the only way to do this commercially was to allow the water which

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had been treated with ozone to trickle over sluices a number of times. Of course, for war purposes the use of ozone was absolutely out of the question; it would entail electrical manufacture on the spot. Liquid ozone did not lend itself to transport and it was quite unsatisfactory for any possible field use.

Mr. Reuss (page 1181) had spoken about the alteration of the pressure of water in the mains affecting the amount of chlorine which went into it; in other words, Mr. Reuss asked how one should regulate the amount of chlorine going into a varying supply of water. That evening he had only described the simplest type of chlorinating apparatus that was in use for measuring chlorine, and if any of the members were interested in this work he would refer them to The United Water Softeners, Ltd., of Imperial House, Kingsway, London. He had nothing whatever to do with that Company, but he would like to give the members an opportunity of getting information on this subject, and if they would refer to that Company no doubt a booklet dealing with the Wallace and Tiernan chlorinating apparatus containing diagrams and illustrations would be forwarded on request. Among those diagrams would be found one of an automatic control apparatus, in which the flow of the water passing through the chlorinating chamber controlled automatically the amount of chlorine passing into that water. It was called the Automatic Control type. The type described in the Paper was of the Manual Control type.

He imagined the question about measuring chlorine when diluted with inert gas was put because there was some little difficulty in reconciling the fact that a gas could enter water and be dissolved and give a uniform solution. Perhaps he ought to describe the diffuser through which the chlorine actually passed as it went into the water. This consisted of a cylindrical porcelain ring about the size of a watch, with two circular disks of alundum cemented together. The substance alundum was very permeable and allowed gas to pass through it in very tiny bubbles. In his experience the greater portion of the sterilization was carried out immediately those small bubbles of chlorine, having of course a larger surface area, passed into the water. He had tried experiments and found that to be

the case. The chlorine at the instant of solution was in a very active state and appeared to be capable of rather more quickly sterilizing water than when already in solution—that is, when it was first dissolved in water and then added. The objection to the addition of a neutral gas to chlorine was fairly simple. It was not an easy matter to mix an inert gas with chlorine, and to be sure of the proportions. If he might take nitrogen as an example, one could not carry about liquid nitrogen; one might take compressed nitrogen, but it was adding considerable complication, and there was no advantage gained by so doing. The whole process depended on knowing that they were using pure commercial chlorine as delivered from manufacturers in the Cheshire district.

With regard to the question why chlorine was measured as a gas rather than as a liquid, perhaps he had not made it clear that the quantity of chlorine used was extremely small. For chlorinating the supply of a town, one-half of one part per million parts of water, that is to say 0·5 part of chlorine per million parts of the water to be treated, was the amount used.

Mr. Daniel Adamson inquired if these proportions were by weight?

Captain Arthur replied in the affirmative.

A Member further asked if the chlorine was added as a liquid or gas?

Captain Arthur replied that it was added as a gas, by weight.

Roughly speaking, two and a half ounces of chlorine (which was not very much) would occupy a volume of three quarters of a cubic foot—71 grams of chlorine having a volume of 22·4 litres at N.T.P. It was very much easier to measure a large volume subdivided than a small weight subdivided.

The Chairman had asked whether he could give details as to the cost. He was sorry he could not do so. Had he known

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that information was desired, he would have brought some figures with him. However, he could give some estimate. Chlorine, when purchased for the Army, cost $2\frac{1}{2}d.$ per lb., and he thought it worked out that the cost of chlorine as a sterilizing chemical, using three parts per million—he was speaking in round figures—was one penny for treating 13,000 gallons of water. It was found in France, that working on the ordinary water supply—not very bad water—a cylinder of chlorine treated about four million gallons of water. The cylinders varied somewhat, but the amount of chlorine used was extremely small. He could not give any figures as to the cost of pumping, which would vary with the type of apparatus used

There was a question regarding the relative weights of chlorine and water used. Roughly speaking, for town's water it would be 0·5 part in one million parts. For the water he was working on at Brentford—canal water and a sewage outfall—about three to four parts of chlorine per million were used. It was very small, and it could only be estimated easily by chemical methods. People had different degrees of taste. He thought the limit of taste for an ordinary person was 0·1 to 0·2 part of chlorine per million. Those who knew the taste and were fresh to it would detect less than that.

The electrolytic process had been used with success for the sterilization of water, and he knew of one or two installations which had been working. He thought it was necessary to keep the sodium hydroxide which was formed at the negative electrode away from the chlorine which was formed at the positive electrode—at the start at all events—and to keep the apparatus cold. A solution of sodium hypochlorite was really made, which was brought into contact with the water, but he believed it was an advantage to keep them separate to start with, to prevent decomposition of the unstable sodium hypochlorite. He was now speaking with some hesitation, because an expert was present who knew much more of the commercial process than he did, but he would hardly have thought it necessary to use the electrolytic process to get rid of the weeds. He did not know the type of weeds, but the ordinary algæ, and such

like things growing in water, could be removed by other chemicals. Probably Mr. Adamson would find it much cheaper to use a method in which most of the material was available on the spot. The method was excellent, for the sterilization of water and chlorine, he knew, had quite a considerable action on growing material.

With regard to the question of chlorine in a town's water supply, he thought it was in the early part of 1918 that he went to Sir Alexander Houston of the Metropolitan Water Board and saw an installation at Hornsey where chlorine was being used to sterilize the flood water from the river, which formed part of the Metropolitan Water Board's supply; he spoke very well of it, and adopted the method as a safeguard against being overwhelmed on his filter beds by flood water. Some friends of his (Captain Arthur's) lived near the reservoir, and their water was drawn from these works. They knew that he was interested in water chlorination, and they suggested that a peculiar taste which the water they were using suddenly possessed was due to chlorine. He found the taste was not that of chlorine. He could not taste it, but they insisted that it was chlorine, so the water was analyzed, but no free chlorine was found. He imagined that the taste was due to some other action and not to chlorine at all, because it passed away quite rapidly, and he never heard any more complaints.

Some time ago he heard a man speak on this subject, and say that when he first tasted chlorinated water he felt violently sick. It was 0·3 part in a million parts. But after a few days he no longer knew that there was any chlorine in the water, and he complained that they were not sterilizing the water supply. He had got used to the taste of it and did not realize that the chlorine was there, which was generally the case with a small quantity of chlorine, as the palate became accustomed to it. He remembered one occasion when he was showing a water sterilizing machine at work to some officers of one of the Allies. The man in charge of the machine passed out a sample of water to taste, and by mistake he took it from the filtered water supply before any chlorine had been added to it. The officers said they could taste the chlorine in it, and were quite sure there was chlorine in it, but there was

(Captain J. Stanley Arthur.)
no possible trace of chlorine there at all. It had a flat taste due to being rather stagnant. When they were given the water that actually contained chlorine, it was sparkling; they thought it was excellent water, and made no objection to it.

If one took water which was not too stagnant, which was only full of ordinary dirt—that is to say, dirt from roads and streams, refuse carried in by rain-water—and it was treated with chlorine and sterilized, and after that, dechlorinated with sulphur-dioxide gas, he was perfectly certain that, providing the operation was carried out with a reasonable amount of skill, there would be no unpleasant taste noticeable. The skill was not very great. During the War, three to four weeks' training rendered the average man quite sufficiently skilled to carry out the process, and there was no real difficulty in it at all. It was different when sewage, sewage effluent, or the water from cesspools was to be sterilized. He had had to deal with water from stagnant pools, which had been stagnant for years, and which was filthy with both animal and vegetable refuse, from rubbish thrown into it, and then in such a case he did not think it was really possible to get rid of the flat taste which was there.

There was a chemical point which perhaps no one had actually brought forward. He rather expected the question to be asked, and he would like to answer it as though it had been put. What happened to the chlorine and the sulphur dioxide? They were present in such minute quantities that they were not tasted. The chlorine reacted with the sulphur dioxide and formed hydrochloric acid and sulphuric acid—two acids which were distinctly unpleasant, but in the very small quantity represented by the dilution they were untasted. Water, generally speaking, contained calcium and magnesium bicarbonates—that is, the water was "temporarily hard." By the action of the hydrochloric and sulphuric acids on this, calcium and magnesium chlorides and sulphates were produced and carbon dioxide liberated. The carbon dioxide converted the water into very weak soda water which sparkled—that is to say, rendered the water bright. The chemical substances produced were quite harmless, as they were of the nature of Epsom salts.

The CHAIRMAN, in moving a vote of thanks to Captain Arthur, remarked that he had turned what might have been a very technical Paper, and rather dry on that account, into a most interesting and lucid account by which he had brought home to the members the question of the water supply to troops in the late War.

Mr. J. PHILLIPS BEDSON, in seconding the motion, said the Paper was highly interesting in every way. It showed, as the Chairman had said, that necessity was the mother of invention. It had been given in a lucid manner, which could be understood by the non-technical side, and it had been listened to with very great pleasure. He was glad also to know that there was somebody present who had something to do with supplying the water-filters used before the War, and who had contributed to the discussion.

The Vote of Thanks was passed unanimously.

Communications.

Brevet-Major H. H. BATEMAN, R.E., wrote that he had had experience of chlorinating plants on four occasions, as under :—

(*a*) *At Haringhe* (*military*) *Waterworks in Belgium.*—Foul water, taken from the Yser, was treated with alum, and then passed through sand-filters or " Bell " filters of small capacity (relatively). Water from the sand-filters, after passing a rectangular measuring notch, was led through a wooden flume 12 inches in section, to the contact tank. The chlorine diffuser was let into the 12-inch wooden flume, and was 30 feet from the actual chlorinator. The apparatus gave extremely good accurate results. As pointed out by the Author, it was necessary to keep the chlorinator at a certain temperature to avoid condensation of the gas and irregular working.

This plant was for 12,000–20,000 gallons per hour. Frequent tests by the medical authorities showed that the sterilization was complete, and that the resulting sterilized water could be practically

(Brevet-Major H. H. Bateman, R.E.)

freed from any trace of chlorine, even without the use of SO_2. Sulphur dioxide was not used in this case, as the medical authorities insisted on the water taken from the pipe-line being treated with bleaching powder, in the effort to avoid contamination from dirty vessels, so the taste of chlorine was unavoidable.

(*b*) *At Rosbrugge* a 6,000 g.p.h. mechanical filtration plant (Bell filters), taking water from the same sources as (*a*), which worked equally well.

(*c*) *At Zuytpeene* (*France*) a 6,000 g.p.h. Mather and Platt mechanical filtration plant. This took its water from a very foul old chateau moat, which, although cleaned prior to the installation being made, still contained the accumulated filth of ages. The water was successfully purified there; but, although free from bacteria, was always unpalatable. An additional alum sedimentation tank would perhaps have improved matters; the alum in this case was fed into the suction of the pump which pushed the water through the filters; and its time of action was of course limited.

(*d*) *Ypres Town Waterworks.*—Contaminated water from Dickebush and Zillebeke Lakes was led to Ypres Prison and subjected to alum sedimentation (24 hours) in 100,000 gallon sailcloth tanks which were put in the old, shell-pierced, open reservoirs. The settled water was taken over a weir to the suction-pump, and the diffuser placed in the suction-pipe of the pumps, which pushed the water forward. There was no contact tank: passage through 7-stage centrifugal pumps and 2 miles of pipe-line were considered sufficient. The water dealt with here was 12,000 g.p.h. The operation of the plant commenced in the winter 1917–18, and great difficulty was experienced in obtaining equal distribution of gas, in spite of all precautions. The German advance put an end to experiments which would doubtless have been successful.

The Author laid rather much stress on the fact of these plants being *standard* for all large water-supply installations in France. At the end of the War the writer's (E and M) Company was working eighty-two pumping plants. Of these, three only were provided with gas chlorinators. The average yield of the plants so provided was greater than 1,000 g.p.h., i.e., than the output of the largest

lorry installation so provided. It was considered that it was only worth while installing these chlorinators in lorries and very permanent stationary plants. The remainder of the drinking water installations, however large, could be dealt with quite well by bleaching powder.

Captain ALEC C. JARVIS wrote that he was particularly interested in Captain Arthur's Paper, because he had had the honour to have carried out the mobile barge plants and the stationary land plants mentioned on page 1140, and illustrated on pages 1142–3, and had had the pleasure of seeing them at work in Mesopotamia. The accompanying photo, Fig. 22, Plate 25, was taken of one of the barges at work on the Tigris. These vessels were quite an appreciable size, being over 160 feet long. Much of interest could be written of the scheme as a whole, numbering as it did some twenty-four complete floating and land units and considerable auxiliary plant.

Not the least of the features of general interest was the voyage out to the East of the first four vessels; later floating plants were shipped knocked down, the barges being specially constructed for re-erection, but the first four were built into large converted dumb barges of Belgian or Dutch type. Each of them, manned by a small crew of N.C.O.'s and men of the Inland Water Transport Branch of the Royal Engineers, ballasted with coal in bags and in tow of a deep sea tug, had adventurous voyages, but in spite of submarines and bad weather they all eventually reached their destination; all credit to the handful of brave fellows who manned them.

On one of the voyages, owing to stress of weather, the tug's limited coal supply gave out before a port could be made, and in a heavy sea the ballast in the barge was opened up and coal passed to the tug to enable her to make port. On another, a barge that had become strained and leaky owing to bad weather was only saved by the N.C.O. mechanic starting up the oil-engine and main pumps, and keeping them going until port was reached. In anticipation of such a contingency, the writer had arranged for the necessary pipe-connexions and fuel supply to enable the plant pump to be used as an emergency bilge-pump. The plants sent to Mesopotamia did not suffice by any means to provide a universal

(Captain Alec. C. Jarvis.)

supply of filtered water, and many depots, camps, etc., were furnished with water treated by more rough-and-ready methods; for instance, many small supplies in the vicinity of Basra were pumped from the river and hand-dosed in tanks with alumina and chlorine, and settled.

Bleach was used and good work was done with it. A laboratory was set up by the R.A.M.C., where the bleach was tested and daily made up into standard quantities in bottles; the chemist officer in charge then visited the supplies in a motor-boat, accompanied by an orderly and the bottles of strong bleach mixture, and dosed the tanks with the required quantities. The writer well remembered, while in that land of heat, dirt, and disease, meeting a friend of his one morning, who was at the time in charge of such work, and he laughingly referred to it as his "milk-round"; only a few days afterwards he made the great sacrifice. The filter barges sent to France had the honour of being "Mentioned in Dispatches," as well as suffering casualties to their number. Chlorine gas for sterilization was used throughout the Mesopotamian series of plants, with bleaching powder as a standby; nevertheless it was emphasized by the writer in his official book written for the guidance of the officers and men in charge of the plants that the greatest care must always be taken to ensure the best possible water bacteriologically with the ordinary coagulation, sedimentation and filtration facilities, as the exigencies of warfare might at any time cause a cessation in the supply of gas and bleach.

It was true, as the Author stated, that filtration could not wholly remove the bacteria, but in the writer's opinion one did not chlorinate a water to sterilize it, but to ensure that no bacteria of a pathogenic character survived in the water as delivered for use. The term "Sterilization" was misleading—very few samples of water treated by chlorination in practice were sterile, nor need they be—so long as there were none of the ubiquitous and indicative B. Coli in 100 cm^3 the water was absolutely safe, and with chlorine this result could be reliably achieved without employing doses sufficiently great or periods of contact sufficiently long to kill the more resistant spores of harmless water bacteria.

There could be no doubt that liquefied chlorine gas was far preferable to bleach in every way, but the writer could not agree with the Author that the residual taste present after treatment with bleach was absent with liquid chlorine; this point had been investigated in America, and it seemed to be established that the residual taste was practically the same in both cases, other conditions being equal. What doubtless did happen, especially under war conditions, was that the superior control and the definite strength of the gas enabled much greater nicety to be used in the treatment, and therefore residual chlorine could be reduced to a minimum. Chlorine gas in cylinders was quite safe and easy to handle; the writer sent hundreds of cylinders to Mesopotamia without receiving any complaint, and tons of it were sent all over America, yet there were in Europe to-day shipping companies who refused to carry it. If the gas escaped, it was not pleasant, as our late foes could testify; it was one of the first gases we used in trench warfare, yet familiarity bred contempt. The writer recollected, when testing some instruments in very cold weather, that the chlorine cylinder was set on a glowing coal brazier to "warm up a bit" before connecting up.

The Wallace and Tiernan apparatus was used exclusively by the writer; it was thoroughly examined and dissected, and was found undoubtedly superior to any that had been brought to his notice. The description of the working of the "Compensator" given in page 1136 of the Paper was, in the writer's opinion, not quite clear, and did not bring out what the exact function of the Compensator was, namely, to maintain a constant pressure-drop across the valve E.

With regard to the difficulty in deciding what quantity of chlorine to add to a water to effect the desired result, without having recourse to trials controlled by bacteriological examinations, the method given in the Appendix (page 1149), while extremely valuable, could not be said to be universally reliable. The presence of chlorine in a water after half an hour's contact was no guarantee that the water contained no B. Coli.

As an illustration of the unreliability of working only upon free chlorine estimations after contact, the following figures were

(Captain Alec. C. Jarvis.)

given from one of the tests made in England with a filter-barge upon a river water :-

TESTS BY CAPTAIN J. N. SUDGEN, LATE R.E., B.Sc.

Chlorine Gas in Parts per Million.

(a) Chlorine Injected.	(b) Chlorine immediately after Injection.	(c) Chlorine after Contact.	(a–b) Immediate Absorption.	(b–c) Contact Absorption.	B. Coli.
5·0	2·45	1·05	2·55	1·40	Absent.
3·75	2·0	0·8	1·75	1·20	,,
2·5	1·6	0·55	0·9	1·05	,,
1·75	1·0	0·65	0·75	0·35	,,
1·25	0·70	0·65	0·55	0·05	Present.

It would be noted that B. Coli was present in the last case where the excess chlorine after contact was 0·65 and absent in the previous two cases, where the excesses were 0·65 and 0·55 respectively; the contact absorption, however, was only 0·05 in the non-sterile sample, whereas it was 0·35 and 1·05 in the other two. The amount of chlorine instantaneously absorbed was remarkable.

In the writer's opinion, it was in the figures for contact or time absorption that one could perhaps look for the promise of a speedy and reliable test for the control of chlorination under practical working conditions. It was found, for instance, in two different cases of filtration and chlorination of grossly polluted river waters that, if the amount of chlorine added was such as to permit during the period of contact an absorption of 0.5 part per million, then the treated water contained no B. Coli in 100 cm^3.

The writer would very much like to see exhaustive research carried out to determine the value of the above method of deciding the chlorine dose without bacteriological examination. The quantitative chlorine estimation was quite simple and could be carried out by any intelligent filter-plant attendant.

There was a slight inaccuracy on page 1141 of the Paper, regarding

sedimentation with the floating stationary plants; the water after the addition of the coagulating chemicals did not stand for some time, the whole process, including the sedimentation, being continuous in the usual modern manner.

The writer would like to associate himself thoroughly with the Author's remarks regarding Colonel Sir William Horrocks. The writer's work came under Sir William's official inspection, and he (the writer) would always remember the Colonel's devoted work and his unfailing kindness and courtesy to all, down to the humblest sapper, who came into contact with him.

Major C. C. B. Morris, M.C., R.A.S.C., wrote that No. 1 Water Tank Company, which went to France in the early part of 1916, was the first systematized attempt to deal with the supply of water by mechanical transport at the Front. The establishment of the Company was as follows, as far as the water equipment was concerned :—

1 30-cwt. Lorry for Chemicals.
111 1-ton Water Tank-Lorries, each containing 150 gallons.
20 3-ton Lorries, each containing 500 gallons.
15 Sterilizing Plants on 3-ton Lorries.
9 Poison-eliminating Plants on 3-ton Lorries.

The above establishment was increased before the Somme offensive in 1916 by the addition of 144 3-ton extemporized tank-lorries, each being fitted with tanks holding 550 gallons.

The sterilizing plants were the old type referred to by the Author, their chief disadvantage being that the rate of delivery was very slow. In other ways the results were entirely satisfactory. The Company, in addition to the A.S.C. officers, had four chemist officers attached, who took charge of all work in connexion with the sterilization of the water. Certain of the de-poisoning plants were fitted up with laboratories, and a large amount of work was done by the chemists in testing the drinking water that was being utilized by the troops in the 4th Army area, to which Army the Water Tank Company was attached on the Somme.

When the Company first arrived in France, owing to its being the first of its kind, and to nobody having had any experience with

(Major C. C. B. Morris, M.C., R.A.S.C.)
this type of transport, numerous difficulties were encountered; for example, it was not realized that the greater portion of the water delivered to the troops would be supplied direct into the tank-carrying lorries from water points under the control of the R.E.'s, without being passed through the sterilizing plants at all, the water being merely chlorinated by the chemists after it was placed in the tanks. This necessitated all the lorries being fitted with their own pumps, the small lorries being fitted with Dando hand-pumps and the large lorries with petrol-driven trench pumps. Official trials took place before the Somme offensive on the 24th May, at Rainneville, and plans were worked out for the supply of 20,000 gallons per day to each of two Divisions. The water was supplied to the tank-lorries by the sterilizers and from a water point about 300 yards off the road, this latter condition being frequently met with under actual service conditions. The method employed in the latter case was to place the small petrol-driven pumps adjacent to the supply of water which was off the road, and to pump the water through canvas hose into large canvas dams erected on the roadside. Additional petrol-pumps were placed adjacent to these canvas dams and quickly filled up the lorries as they came alongside. These trials were witnessed by large numbers of the corps and divisional staffs, who reported favourably on the results. After the trials the lorries were widely distributed on the whole of the 4th Army front, the work being of a dual nature, namely, water sterilizing by the sterilizing machines and water carrying by the tank-lorries. Frequently the water sterilized was delivered direct into water-carts or other receptacles, whilst on the other hand much water was carried by the tank-lorries, which was obtained from other sources than the sterilizing machines, that is, the stand-pipes erected by the Engineer services and fed by pipe-line installations. In many instances the water-tank lorries saved a critical situation during the Somme battle, by carrying water from the water-points in the rear into the concentration area, where the Engineer pipe-line services had been hit by shells, or otherwise put out of action. This occurred at such places as Fricourt, Montauban, Longueval, and Becourt. On other occasions the sterilizers were able to establish a water point from a dirty stream or marsh, where

it would have not been feasible for the Engineers to put in a pipe-line or well-supply of good quality; for example, at Etineham, Allonville and Poulainville, Meault and Derancourt. It was soon found that the sterilizers often could not approach near enough to the water source to get to work, so that auxiliary pumping sets were installed in such places, which pumped up the water into a canvas dam of about 2,000 gallons capacity, the latter being fixed up wherever required. These canvas tanks were of great use all through the campaign, and were an invaluable asset to the sterilizing machines.

An actual instance of the conditions under which the lorries worked might be of interest. Within twenty-four hours of the first advance on the Somme, canvas dams had been erected in Fricourt, which was in the old German lines, and were kept filled by the tank-lorries obtaining their water both from sterilizers and from the R.E. water-points, this being the only drinking water adjacent to that area. One of the greatest difficulties that the Company had to contend with was the condition and congested state of the roads. It was here that the small 1-ton lorries proved invaluable, as they could cover ground where it would have been extremely difficult or impossible for 3-ton lorries to have been used. At this particular water-point, in order to keep up the supply of water, the section of lorries detailed for this work at Fricourt were working continuously for three days and three nights. In addition to supplying sterilized water during the Somme battle, the large tank-lorries carried water for horses, locomotives, and baths.

During the severe frost in February, 1917, all the sterilizers had to cease work because the water froze in the piping even whilst running. Considerable trouble was experienced with tank-lorries also which froze almost solid, if left stationary and full of water.

Mr. R. Edgar Taylor wrote that as the Author made no reference to the steam-plants which were in use by our Army, the writer drew his attention to the fact that a number were made and despatched to the various fronts by Messrs. John Kirkaldy, Ltd., similar to the one shown in Fig. 23, Plate 25. In addition, two sets of quadruple-effect distilling plants, capable of producing 100 tons of pure distilled water every twenty-four hours, were

(Mr. R. Edgar Taylor.)
made and despatched to Egypt. One set was badly shelled by the Turks, when being erected at Gallipoli, but the other was erected completely and proved quite satisfactory. A similar set was erected at the Immingham Docks for Admiralty purposes, and gave every satisfaction.

The AUTHOR wrote, in reply to the communications, that Captain Jarvis referred (page 1192) to the misleading usage of the term sterilization. Throughout the Paper the accepted meaning had been adopted, as explained. Water which did not contain B. Coli in 100 cm^3 was termed sterile. With regard to the figures of chlorine absorption, obtained by Captain Sugden, they were known to the Author and only served to confirm the results of many experiments carried out soon after this work was commenced. No mention of this was made, for the reason that the Paper only aimed at giving a description of the process and the apparatus used. Experience in the field showed, however, that for all practical purposes the chlorine estimation by the "Case, Water Testing Sterilization" was sufficient.

Major Morris (page 1195) had not stated the composition of No. 1 Water Tank Company quite correctly. This company and also No. 2 Company had each nineteen sterilizing plants and eleven poison-eliminating plants. The establishment of No. 1 Company was incomplete as regards one sterilizing plant until the original Chlorine Gas Sterilizing Plants were sent out. Nos. 3 and 4 Water Tank Companies were composed of fifteen sterilizing plants and four mobile laboratories. No poison-elimination plants were used. During the severe frost mentioned, the chlorine gas sterilization plants were in some cases kept at work, the R.A.M.C. officers in charge wrapping, very thickly, all exposed parts with straw and sacking. The nominal output of these plants was rated at 1,200 gallons per hour, but in actual service a greater output was often maintained. They had been known to deliver twice this quantity for twenty-two consecutive hours per day for many days together.

A few distilling plants were sent out to Egypt, but they were not under the control of the R.A.M.C., but of the R.E. Sedimentation, filtration, and chlorination—either by bleaching powder or chlorine gas—were the principal methods in use for the sterilization of water.

The Institution of Mechanical Engineers.

PROCEEDINGS.

3rd December 1920.

An Extra General Meeting was held at The Institution, London, on Friday, 3rd December 1920, at Six o'clock p.m. Captain H. Riall Sankey, C.B., C.B.E., R.E. (ret.), *President*, in the Chair.

The Minutes of the previous Meeting, held on 19th November, were read and confirmed.

The President announced that the following 136 Candidates had been duly elected:—

MEMBERS.

Allen, Rupert Stanley,	Bedford.
Buckley, Arthur Edward,	Malta.
Burkinshaw, Henry,	Calcutta.
Crowe, Henry,	Saltburn-by-the-Sea.
Cunningham, George Hamilton,	Melbourne.
Davies, Percy George, Lt.-Col., C.M.G., R.A.O.C.,	Berlin.
Davison, John William, M.B.E.,	Pontypridd.
De Lisle, Godfray,	Lincoln.
Gallinagh, James Patrick,	Singapore.
Hand, Thomas Wilton,	Sheffield.
Hawkes, Charles John, Eng. Comm., R.N. (ret.),	Newcastle-on-Tyne.
Head, Ernest Wilfred,	Colombo.
Hopkins, William Henry,	Southport.
Hudson, Noel, Major, D.S.O., R.A.,	Wool.
Jones, Edwin Walter,	Lincoln.
Marsland, John,	London.
Pletts, John St. Vincent,	London.
Pring, John,	Lincoln.
Reeves, Edward,	Tirau, N.Z.

Ridlington, Joseph, ... London.
Ryan, John Willetts, ... Lincoln.
Seddon, Henry, ... Huddersfield.
Spyer, Arthur, ... London.
Tweedlie, John Reid Groundwater, . . . Shanghai.
Whittaker, Thomas Alfred, ... Nairobi.
Witchell, Edward Frank Dalby, ... London.
Wraith, Herbert Osborn, Major, ... Leigh.
Yarwood, Albert, ... Northwich.

ASSOCIATE MEMBERS.

Barnes, Frank Purcell, Major, R.A.S.C., . . . Aldershot.
Borwick, Thomas Faulkner, Lt.-Col., D.S.O., . . London.
Boyce, Sydney Robert, ... Billingham-on-Tees.
Brown, Frederick John, ... Letchworth.
Burton, Bertram Harry, ... Stoke-on-Trent.
Calder, James McLennan, ... Reading.
Causer, Howard William, ... Manchester.
Chell, Thomas Alfred, ... Broadstairs.
Clegg, Fred, ... Manchester.
Cleverley, Harry James, ... Manchester.
Crockatt, William Campbell, ... Glasgow.
Edmondson, Richard, ... Manchester.
Evans, Edwin Blaxley, ... Bradford.
Finney, Sydney Henry, ... Manchester.
Gemmell, Alexander Ramsay, ... Renfrew.
Gomersall, Lawrence Arthur, ... Keighley.
Gregson, William, Major, R.E. (T.), . . . London.
Grugeon, Percy, Lieut., R.A.S.C., . . . Colchester.
Hall, William Ernest, ... Loughborough.
Harley, Gordon, ... Cardiff.
Harvey, George Back, ... London.
Haward, Frederick Bernard, ... Chelmsford.
Hines, Sidney Harry, ... Norwich.
Hyde, Leonard, ... Hull.
Ingram, Harold William, ... Birmingham.
Leicester, Harry Lionel, ... London.
Levett, John Victor, ... Guildford.
Lewis, William John, M.B.E., ... London.
MacKechnie, Joseph, ... West Bromwich.
Mallett, Claud, ... West Hartlepool.
Mellor, George Arthur, ... Cowes.
Mitchell, William Charles, ... Glasgow.
Newell, Percy Bramwell, ... Birmingham.
Newton, Kenneth, M.C., ... London.
Northfield, John Allen, ... Coatbridge.
O'Mahony, Charles Carleton Saunders, Major, R.A.S.C., Aldershot.
Organ, Charles Alexander, Lt.-Col., D.S.O., R.A.S.C., London.
Paddon, William, ... Stroud.
Palmer, Albert Edward, ... Birmingham.
Penn, Bertie Howard, Major, R.A.O.C., I.O.M., . Didcot.
Pullen, James Frederick, ... London.
Rankin, Henry Conder, ... Newcastle-on-Tyne.
Reavell, Kingsley, ... Ipswich.
Richardson, Cecil George Herbert, ... Newark-on-Trent.
Sams, Charles Egbert Reynolds, ... London.
Segrott, Robert Francis, ... Birmingham.

Skinner, Alec Joseph, M.C., ... London.
Slaughter, Ernest William, Major, M.B.E., R.A.O.C., Kantara.
Stamp, Samuel Herbert, ... London.
Thompson, William, ... Blackpool.
Thomson, Robert Rowan, ... Rangoon.
Watson, Charles Collinson, ... Lincoln.
White, Ernest Dilke, ... Pembroke Dock.

ASSOCIATES.

Birrell, William, ... Loughborough.
O'Riordan, George Francis, ... Hull.
Proehl, William Frederick, ... South Farnborough.
Turner, William, ... Grantham.

GRADUATES.

Ash, Edwin Raymond, ... Loughborough.
Atkinson, Alfred William, ... London.
Bendy, Wilfred Richard, ... London.
Benjamin, Alexander Gordon, ... Penarth.
Bethell, Herbert Owen Chinki, ... Leeds.
Billington, Godfrey Turner, ... Wolverton.
Blackburn, Frank, ... Leeds.
Blackman, Arthur Edwin, ... Loughborough.
Blizard, Charles Hillyer, ... Ventnor.
Bonney, Robert John Ball, ... London.
Broadley, Edwin William, ... Coventry.
Burkett, George Thomas William, ... Birmingham.
Butler, Harold Guy, ... London.
Butters, John Harlow, ... Nottingham.
Carter, William Dennis, ... London.
Clarkson, Frederick, ... Watford.
Coombes, Lawrence Percival, ... London.
Cooper, James Bruce, ... Southampton.
Davis, John Stuart, ... Salzburg.
Douglas, Robert, ... Workington.
Fiddes, John Stuart, ... Bath.
Giddings, Herbert Charles, ... Newport, Mon.
Hanman, John Lionel, ... London.
Innes, James William, ... Swindon.
Jackson, Arthur Norman, ... London.
Longley, Philip Augustine Allnutt, ... Upper Slaughter.
Mountain, Stephen Reginald, ... Southampton.
Page, Alfred Cyril, ... London.
Pank, Herbert Abraham, ... Norwich.
Parry, Eric Meirion, ... Rock Ferry.
Parsons, Archibald Frederick, ... Swanage.
Puryer, Percy Leonard, ... New Brad well.
Reid, Logie Goldie, ... Stafford.
Sellman, Thomas Douglas, ... Reading.
Slattery, Lewis, ... London.
Soper, Stanley William, ... London.
Stark, William Harry Charles, ... Birmingham.
Stowers, Arthur, ... Bedford.
Stoyle, Clayton Cobb, ... Bath.
Sumpner, Philip John, ... Southampton.
Swann, Alec Hanbrey, ... Chichester.

Taylor, George,	Leeds.
Thompson, Vincent Swire,	London.
Tomlin, William,	Darlington.
Turner, Eric Hugh,	Hove.
Turner, Lionel Alfred,	Bath.
Twinberrow, Ralph Wulstan Kimberley, Eng. Lieut., R.N.,	London.
Urwin, Cecil Roland,	London.
Waghorne, Harold,	Ashford.
Walsh, Edwin Lawrence,	London.
Walsh, Henry Thomas,	London.

The President announced that the following twelve Transferences had been made :—

Associate Members to Members.

Bazin, John Ralph,	Dublin.
Bell, John,	London.
Browne, Alexander Fleming,	London.
Buckton, Ernest James,	Buenos Aires.
Chubb, Harry Emory, O.B.E.,	London.
Craven, Arthur Douglas,	Oldbury.
Fox, Samuel Alexander,	Newark-on-Trent.
Gow, Walter,	Howrah.
Miéville, Arthur Leonard, D.S.O., M.C.,	Bolton.
Taylor, William Arthur Trevor, M.B.E.,	London.
Valon, William Argentine McIntosh,	Stafford.
Williams, Charles,	Cardiff.

The Discussion was resumed on the following Paper which had been read and partly discussed at the Lincoln Summer Meeting (page 709) :—

"The Human Factor in Industry"; by Alexander Ramsay, of Lincoln.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 76 Members and 17 Visitors.

THE HUMAN FACTOR IN INDUSTRY.

By ALEXANDER RAMSAY, of Lincoln.

Discussion in London, 3rd December 1920.

The President called upon Mr. Alexander Ramsay to make a few opening remarks in connexion with the Paper which he had read at the Summer Meeting of the Institution at Lincoln (page 709).

Mr. Alexander Ramsay said that, in dealing with the question of the Human Factor, it was desirable that the members should keep in mind the larger and the fundamental issues, but, as it was his duty only to open the discussion, he thought probably, if he were to refer to one or two of the circumstances with which they were at present faced, it might be the best means of leading to the bigger issues he had indicated. At the Summer Meeting held at Lincoln, he had referred to the fact that large sections of industry were drifting into a position which was economically unsound, and the history of the past few months had, he thought, more than justified that point of view. Owing to a combination of circumstances—rates of exchange, international credit, the state of world markets, and other influences, most of which had their root in the cost and volume of production, this country was faced at present with probably the most gloomy outlook it had experienced for a generation. That would appear to be a good time in which to test the attitude of the worker and the employer to each other, and, whilst he was not going into detail, he would like to point to one or two circumstances which would test the attitude towards the fundamental economic considerations with which they were faced.

(Mr. Alexander Ramsay.)

The strongest argument which the workers had put forward in recent years for improving their wage condition had been on the ground of the cost of living. That was a very serious argument, but they had been content to ignore, and the Government and the employers had been content to let them ignore, the fact that the cost of living was not a kind of blind fate from which there was no escape, but that it could be controlled by agencies which were more or less within their own reach. High wages—which no one would quarrel with in a proper setting—reduced working hours and decreased effort, had all tended to increase the cost of production, which was on a very high level. He suggested that it was simply ridiculous to imagine that this country could send exports abroad at a very high price and believe that the people to whom it exported were going to send cheap food in return. At one period this country sent very large quantities of coal to South America and the ships brought back wheat. The price of English coal had been raised to such an extent that it became cheaper to buy coal in North America, with the result that we sent ships in ballast to the Argentine to bring back wheat, and that wheat, of course, had to stand the cost of the double freight. In view of those circumstances, it was quite easy to understand one of the reasons at least why the cost of that particular product had increased; and so it went on.

Employment was affected in a precisely similar way. There had recently been a break in the tea and rubber markets, and what was the result? This country wanted those commodities as cheaply as they could be obtained, but we had been trying to sell to the people who produced those commodities English machinery at the very high price we were forced to charge. That of course could not be done, and the result was that the growers and the planters had ceased to order, and the men who were engaged in making that machinery were out of work. That was a situation which he thought was typical and very general, and, while it had a very serious effect upon the profit-earning capacity of the country, it had a still more serious effect upon the workers themselves, inasmuch as in countless cases it took from them their means of

livelihood, and in many places reduced their standard of comfort. One would imagine that in such circumstances the employer and the worker would be deeply concerned to see what they could do by joint action and enthusiastic co-operation to ease the rigours of those circumstances, but it was found in point of fact that there was such a widely different point of view and so slightly developed a sense of responsibility that, while employers all over the country were shutting down factories, the leading Trade Unions were asking and insisting upon a very large increase in wages. The significance of that fact lay in the indication that those who could in so large a measure influence the destinies of industry, either had not experienced the steadying effect which their responsibility should carry, or simply did not understand those very delicate factors which made for the prosperity or otherwise of industry. He did not wish to magnify the difficulties.

There was no doubt at all that the country was passing through a very troublesome phase of the social and industrial development of the worker. For a very long period the worker had been struggling for recognition, and he had got consolidation and power so suddenly that he himself was a little embarrassed. The speaker thought there was no doubt that that phase would pass, but he suggested that it raised a question of the most supreme importance, namely—Was the new phase to lead to a better understanding between the worker and the employer and to a better, more scientific, and happier organization of the present system of industry; or was it to lead to a definite joining of issue with those who advocated the socialization of industry, amongst whom were many in the ranks of the younger Trade Union leaders?

There was a complacent feeling abroad that recurring labour crises took place; that in the past we had struggled through; that we should have them again, and no doubt a way out would be found; but he ventured to suggest that the position at present was much more serious and dangerous than that, for the following reasons. The community was demanding that industry should support it in a state of comfort which could only be attained by real hard work and excellent organization; and if that standard

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of comfort was not attained, there was more than a possibility that it might lead to blind reprisals. In the second place, a great many of the Trade Union leaders and countless numbers of the rank and file of the Trade Unions were imbued with the definite ambition of attaining State control, and that meant that they were doing their very best to disparage and to breed discontent with the present arrangements. In the third place, he thought the members would agree that the class consciousness of the worker was much more highly developed than it ever had been, and that, of course, was going to lead to a consolidation of power and to more unanimous action. In the fourth place, the real power, political and industrial, of the worker was much stronger now than it had ever been in the history of the country.

The autocracy of capital, if it ever existed, had disappeared and care had to be taken that it was not replaced by the despotism of a section of labour. The mind of the country had got to be clear on that issue, and its will must be strong. If the community realized that they could not consume unless they produced, and if they believed that a really honest attempt was being made to give the worker, to quote an old expression, "his proper place in the sun," he did not believe they would have very much to fear. He thought half their troubles arose from the absurd idea that there was an illimitable store of the necessaries of life, which could be brought into use, not through work, but through the political and industrial ascendancy of those who subscribed to certain doctrines. If that idea could be dissipated and if the country could settle down to honest work, he thought there would be at least a chance of obtaining that happier state of affairs which they all desired to see. He therefore suggested that employers and those who were responsible for government should take every opportunity of demonstrating, not only to the Trade Union leader, but to the individual worker, that he and they were in the grip of economic forces from which they could not escape, and that the only hope of security for them both was to co-operate earnestly and honestly for their own good and the good of the whole community. He thought that point could not be emphasized too much. It was

necessary to educate, to propagate that doctrine through the Press, and personally through every channel at their command, in order to bring the people of the country to a truer conception of that most important issue. Having done that, it must be realized that goodwill and justice were the only foundations upon which a permanent industrial structure could be reared; and therefore it was absolutely essential that the employers should make it quite clear that they desired to give to the worker that place which he might reasonably expect. If the desire of the employer was merely to hold, of course the desire of the worker would be to attain; and so the struggle would go on. After all, it must not be forgotten that reaction was not firmness, and stupidity was not strength.

His own duty was only to introduce the discussion, and therefore he would not take up time by dealing with any of the proposals which had been put forward to enable a better understanding to be reached. Arbitration boards, shop committees, workmen directors, profit-sharing, and so on, all had their advocates and detractors, but what he was concerned to see was that the best minds of the country should address themselves to the closing of the chasm which otherwise must widen, to see that men with good sense and goodwill on both sides (and there were many) should seek industrial good and lead towards it, because he believed that once there was a real will to solve the problem, the common-sense of the country would find the right solution. He believed that, dark as the outlook was, they would yet find workers and employers who would lead their countrymen to a higher conception of their duty to one another, and to a better realization and acknowledgment of their social responsibility.

The PRESIDENT said he was sure all the members would agree with the Author's statement that true co-operation of employers and employees would be the salvation of the situation which now obtained in this country. Could the Institution of Mechanical Engineers help in bringing about that very desirable state of affairs? Personally, he thought it could. At the present moment, however, the Council had not discussed the question in any way, and they

(The President.)

hoped that the opinions expressed at the present Meeting would help them to arrive at some conclusion in regard to the matter. For that reason, it was very desirable the discussion should be quite full and free, but at the same time it was necessary for him to say that speakers must be very careful not to touch on any matters which might lead to the introduction of party politics. Obviously things of that kind could not be discussed at a Meeting of the Institution. With those prefatory remarks he would ask Colonel Carnegie, who was in the Office of the War Cabinet, if he would kindly continue the discussion.

Colonel David Carnegie, C.B.E., F.R.S.E., thought the Author was to be congratulated on having brought before the Institution some of the human problems in industry, and the Institution was also to be congratulated on permitting a discussion of the subject. For the past six years he had been particularly identified with industry in Canada. As a member of the Imperial Munitions Board and as Ordnance Adviser to that Board, he had had in his executive capacity considerable opportunity for dealing with different phases of industry right throughout Canada. Since the termination of hostilities he had been investigating, on behalf of the Canadian Government, the industrial situation in this country, particularly with a view to ascertaining how far Joint Industrial Councils could be applied to industries in Canada.

With these few opening remarks, he proposed to proceed straight to that part of the Paper which dealt with the payment of workers. The statement was made on page 711 : " Most of the great Trade Unions of the country have declared against working a system of payment by result." On the surface one would say that was absolutely correct, but if the Author would permit him he would rather read the sentence in the following way :—" Most of the Trade Unions of the country are not opposed to the principle of payment by result, but to the imperfect systems now in use which embody that principle." He said that because he had been rubbing shoulders with all sorts of men in industry, and he thought if he had been able to gauge the true and accurate opinion of sound

labour—he was not dealing with extremists—it would be more accurate to quote it in the way he had stated.

With regard to the next part of the sentence from which he had quoted, " in spite of the most complete safeguard for the inefficient," he was a little in doubt as to what the Author meant by those words. If he judged aright of the conflict which existed in industry at the present day between the employer and the employed, one of the causes was that the employed did not think there was security for the inefficient against loss. Where were the safeguards to the worker against prices being put on work, either for individual piece-work or for collective piece-work, that could be looked upon as just ? Where were the safeguards to the worker against prices, when set, not being cut ? Where had the worker the voice, that he considered he should have, in determining the price or prices which, in his judgment, were fair for the articles he was called upon to produce ? The present was not the moment to refer to collective systems of profit sharing and bonuses for the remuneration of labour, which made more allowance for the inefficient in the general efficiency of the workers as a whole. What he did believe was that the worker must have more voice in settling what the prices should be for his work, so that he might feel safeguarded against a breakdown in a contract made between him and his employer.

From thirty years' experience of industry and from a study of all the systems that had been introduced for inducing the best from the worker, he believed that no more important subject could engage the attention of mechanical engineers at the present time, who were associated with all phases of industry, than the question of the payment of the workers. He also believed that the system which had a relation to payment by results brought the best out of the worker, increased production in the best way, and was likely to bring national prosperity to the country far sooner than any other system of payment with which he was acquainted. It was also important to think of the defects of the system of payment by results as they appeared to the workers. If the Institution were to be of service to industry in helping to remove the defects of the system, it would be necessary for it to consider the objections raised

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by even the extremists to any system of payment by results, which encouraged the exaltation of the efficient worker and showed up the handicaps of the inefficient. If they were to help the worker who thought that, by encouraging any system of increased production, unemployment would result, it was necessary to go into the matter very carefully and prove to him that production in relation to his reward was always assured, and that some provision was made against unemployment. The suspicions which had grown around those assertions of the workers could only be dispelled by bringing the worker face to face with the facts in the factories, so that he, along with the manager, could discuss the problems there, instead of such questions being discussed by the representatives of both in Whitehall or any other district away from the scene of operations.

He agreed with the Author's statement that the subject was of paramount importance to industry at the present moment, and if the members of the Institution accepted that view, he threw out a suggestion first of all to the Council that some investigation should be made of the different systems of payment by results now in vogue, and that some statement might be given by the Institution in relation to the subject.

Mr. F. S. Button said he was very pleased indeed to have the opportunity of putting his point of view before the members on Mr. Ramsay's Paper, which he had read with very great care, and which the Author had added to with his usual clearness and foresight at the present Meeting. In the first place, the President and the members might be interested to know that for many years he had read the account of the Institution's Proceedings which had appeared in the technical Press, and he was agreeably surprised to learn that the Institution decided to consider what appeared to be the non-mechanical side of the tremendous problem of production and everything incidental thereto in industry. It seemed to him it was a sign of the times that the Institution of Mechanical Engineers had invited discussion on such a Paper, presented in such a way and by such an authority as the Author. He spoke

as a very old member of the A.S.E., although he was in no way representative of them on the present occasion; and it seemed to him that, from whatever standpoint the problem was viewed, a very considerable amount of agreement would be found amongst all men of reason, foresight, and knowledge of up-to-date affairs. If time permitted, he thought it would be discovered that one or two of the points the Author had made were not quite as he presented them.

On the question of systems of payment by results, a very great deal of misapprehension existed as to the attitude of the skilled Unions, at any rate in the engineering and shipbuilding trades. With the exception of the port of Liverpool, practically the whole shipbuilding trade was on piece-work systems and a very great proportion of the engineering trade was working on that or some other system of payment by results. Indeed, it was only because of the imperative need of production at the present time and the desirability of the extension of piece-work, or some other system of payment by result, to cover the whole of the workers, that recently a ballot vote was taken by some of the engineering Trade Unions, but the issue was not by any means a clear one. He thought the Author and the speaker between them might be able to straighten that out. He was able to give the point of view of the operative mechanical engineer on the question. If there were a dozen shops or any number of shops in any given district, and one shop worked on a piece-work system and the others on a day-work system, he could tell the members beforehand where they would find the best, the most vigorous and the most up-to-date workmen. There could not be any doubt at all that the average working man preferred to be paid on a system of payment by results. There were some trades, such as the building trade, which had a long traditional practice, which it brought into that part of the engineering trade which dealt with aircraft during the war—a new trade altogether. The building trade had a traditional outlook—a settled policy—which was opposed to piece-work or any other form of payment by results, but that was a body entirely by itself, with its own peculiar experiences which he thought, if the subject were carefully

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investigated, would justify, up to a point at any rate, their rather insular, parochial and, if the members liked, narrow-minded point of view.

If he understood it aright, the matter which most concerned the present Meeting was to find some way out of what appeared to be at the moment an industrial *cul de sac.* They all regretted the lack of goodwill which appeared to be prevalent between the opposing camps of capital and labour, but if one looked at it very closely indeed, he thought it would be found that there was at the present day a readiness on the part of certain sections of labour to recognize their identity of interest with the capitalist who produced. Certainly the members of the Institution were the men who, in the majority of cases, ran the industry, found the brains and the organizing ability, managed the workshops and produced the goods, probably distributed them, and even found new markets. There should not be any essential lack of unity or interweaving of interests between the factors of production, whether they were managers, foremen, the administrative staff known as the salariat, or the manual workers; and he was satisfied that there was a tremendous reserve of goodwill waiting to be tapped in industry at the present day.

He could not imagine any greater value accruing to any efforts of such a body as the Council of the Institution than a real attempt to find out a *via media,* the opportunity that lay ready to their hands for a way out of the apparent desert of irritation, ill-will, and lack of co-operative effort. He did not think there was a Trade Unionist of any standing who would in any way defend the policy of "ca' canny." During the past week one of the leaders of the Trade Union group in the House of Commons laid down very definitely in a very remarkable speech his point of view in regard to the question of greater production. He was in entire agreement with the Author of the Paper that the whole future of the country depended on a new point of view in regard to the problem of production. The rehabilitation of the country after the war depended more largely on the engineering and shipbuilding trade than on any other, and this country would not improve its position

in the world unless it produced more goods. He did not know if his remarks were of any value, or whether he was addressing himself to the point.

The PRESIDENT, interposing, said that Mr. Button's remarks were extremely valuable.

Mr. BUTTON, continuing, said it seemed to him the important thing for every man interested, not in the welfare of his own shop or his own district, but in the welfare of the nation, was to endeavour to ascertain if there was not some way of getting out of what appeared to be a tremendous industrial *cul de sac.* He agreed with the Author's statement, which after all was a truism, that it was impossible to have more things unless more things were created, and the more things were created the greater would be the reserve from which people could draw the things they needed. He was pretty well assured that there was an enlightened attitude amongst the workers on that question. There was no value in playing the fool and " ca' cannying " in order to find a job for one's mate or for somebody connected with one's Trade Union branch or with one's shop. As far as he understood it, that attitude of mind had, with one or two exceptions, been entirely given up. But a feeling existed at the present time that industry was on a very one-sided basis, that the constitution of industry was wrong. What they ought to do was to find out whether there was anything in the claims which were now being consciously and definitely made by the working man for a higher status in the industry in which he worked and gained his livelihood. The strongest argument at the present day amongst the extremists, the shop stewards and the potential Bolsheviks, was that the working man was in a dependent position who had no absolute and final freedom, that he was a wage slave, that he depended on others for his livelihood, and very often on the caprice of some foreman or manager in a workshop for the continuance of the opportunity of finding bread for his family and himself. Those conclusions were not reached by big bodies of men without there

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being some justification for them, and he was sure that some of the proposals which the Author had touched upon were far more significant and probed much more deeply into the problem than perhaps Mr. Ramsay imagined. For instance, the question of workmen directors, which the Author had touched upon, would be rejected by a great many people. They would say the working man was not fit for such high office, that the working man had got to prove his title to power by acting responsibly with the power of which he was at present possessed. The members probably knew much better than he did the wonderful words of Macaulay, in his Essay on Milton :—" You cannot expect men who have been living in a cave all their lives not to blink when they come out into the sunlight." He thought of the tremendous value in the way of learning and knowledge which was accruing to working men day by day on the Whitley Committees and similar bodies. They sat there cheek by jowl with the employers and the administrative staff, dealing with everyday problems, and it seemed to him that was a phase of the question which ought to be very carefully considered by the Institution, if it proposed to offer any conclusions to the world which would be of permanent value. The Author made a very remarkable statement on the first page of his Paper, which was fundamentally true : " The whole structure of industry is ultimately at the mercy of those who work with their hands." The term used appeared to be a gesture not so much of impatience as of despair.

He was in no mood to despair of the tremendous potentialities of the working man if he were given a chance to prove his value to the industry and to the State, and he felt sure that along some such road of giving the working man a more sure position, a higher status in industry, which would give to him, as it gave to every free man in the ancient civilizations of Greece and Rome and in the old City States, the chance to go from the bottom to the top, so that every boy who was apprenticed to his trade would be a potential member of his board of directors, a solution of the problem would be found. He had got it in the larger world dealing with social and political life. Only in industry did his opportunity and his inheritance

seem to be curtailed. If the responsible men were given more and more equality with those who were organizing, finding the enterprise and the brains for running the industry, and were given a more assured status, calling out all that was best in them, appealing to them as men as good as the organizers themselves—if they were given as good an opportunity of making good as they themselves had had, he was certain that a great deal of the mistrust, certainly the policy of restricting output by which the whole value of industry and the chance of the rehabilitation of the nation was being threatened, would disappear. There was a great reserve of goodwill and co-operative effort waiting to be tapped by those who were willing to give the working men an opportunity and a share in responsibility, power and control, such as he suggested.

Mr. Robert R. Hyde (Industrial Welfare Society) said he had been invited to take part in the discussion. What was meant by the human factor? He proposed to offer to the members a definition which had made a great appeal to him and which he hoped might make an equally great appeal to them. Mr. Jacks, in one of his books, used a wonderful phrase: "Teach us to know each son of man not by a number, but by his name." The Author of the Paper under discussion had spoken of the workers' desire for recognition, and had given him a clue that evening for his remarks—namely, that he believed there was need for filling up the chasm; but how was that chasm to be filled? It was necessary to start at the bottom with the pebbles. There were many to-day who were urging that the question of human relationship—the recognition of the human factor in industry, could be faced, dealt with, and settled by the schemes that already had been outlined—copartnership, profit-sharing, collective piece-rates, and so on; but unless the substructure was sound those great schemes must remain nebulous. It was necessary first of all to get down to the human, to remove suspicion, lack of understanding, and mistrust, and then the superstructure could be built.

The Author stated that the worker regarded the employer as one

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who stood between himself and his rightful aspirations. On the other hand, many employers claimed that it was the worker who was to blame for many, if not most, of the present industrial problems. Each party misjudged the other. To give an exact instance of what he meant, he stated that a short time ago he was addressing an Association of Coal Owners on Industrial Welfare work, and at the end of the discussion the coal owners said: "We are very keen indeed upon this movement, but you will never get round the miners." Shortly after that he addressed a meeting of miners in the Midlands, and at the end the miners said: "We are very keen on this movement and would like to see it introduced into every mine and pit in the country, but you will never get round the owners." That attitude could be found in many directions at the present time, and until lack of understanding had been removed, he did not believe there was any possibility of building a secure and lasting structure. The Author said very truly that the cause of the misunderstanding was the fact that the employer had failed to establish contact with his workers. As a matter of fact, the employers had not failed to establish contact with his workers; he was meeting them, but all too often, across a table when each was trying to "best" the other. The contact was there all right, but it was the wrong kind of contact.

It was necessary at the present day to introduce into every industrial enterprise more personal contact—a much more friendly contact between the employer and his workers. Once goodwill began to find a place, industry would begin to make headway there. How were opportunities to be introduced into each factory by which the employer could meet the workers? During the last four years he had been in very close touch indeed with many hundreds of firms, up and down the country, where that close personal contact did exist, simply because the heads of the concerns had provided opportunities for its expression. As a simple illustration of his meaning, he stated that he visited one of the South London works not very long ago. The occasion was the unveiling of a War Memorial, and during the evening the head of the firm presented gold rings to two of his workers who had just completed fifty years'

service. It was a spontaneous action; a little personal incident; but it served to create a very pleasant feeling in the company. The concert which had been arranged was about to begin when one of the workers came through a door at the back of the stage, carrying on a tray a beautiful tea and coffee service; he approached the head of the firm and said: "Sir, we worked hard all through the War, and we know what hard work means, and because we know what hard work means we know just what the War has meant to you. You have kept the whole concern going and have worked harder than any of us, and we want you to accept this little gift." If that kind of personal goodwill and good fellowship existed in places of business, it would prepare the way for greater issues. In some of the large firms at the present time, where it was quite impossible for the head of the firm to meet his workers, he had introduced the personal element by means of a proxy, who dealt with various activities. For instance, the exact method by which the new worker was introduced to the shop could be made a very useful channel for showing him that personal interest was taken in his well-being; the careful watching of the progress of juveniles, so that when promotion was made, it was dependent upon justice and fair dealing and not upon favouritism or the friendship of a foreman; the field of health, and accident; the conditions under which people were working in the shops were all available means by which masters and workers could meet. He came across a case recently where in one of the ship-yards the directors wished to provide an ambulance station for the workers. It was suggested at the Workers' Committee that if the workers would provide an ambulance squad, the firm would provide the room and a staff of nurses. Not only did the men provide the squad, but they raised enough money to buy a motor ambulance. These were little things, but they were preparing the way for greater things.

All over the country at the present day, in firms of every description, the masters and the workers were finding common ground in the occupations of their leisure hours. Whatever might be done in the future, one factor had to be remembered—that as mechanical operations increased, as the worker was reduced more

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and more to becoming a part of the machine, something must be introduced in order to break the monotony and to give recognition to the human factor in the worker. In connexion with such activities the "man to man" attitude could once again be built up.

The Author had referred to the growing popularity, as a means of communication between the head of the firm and his workers, of the House Organ or Works Magazine. During the last two years a wonderful development had taken place in that particular direction, and at the present time there were nearly two hundred firms which published and maintained their own House Organ. In a few days' time a Conference would be held in London, under the auspices of the Society he represented (at which a Member of the Council of the Institution, Mr. Pendred, was going to speak) of some fifty or sixty editors of those Organs, with the object of discussing ways and means by which they might become more effective instruments of goodwill. That was one little detail in a great subject, and he had only referred to it because it was mentioned in the Paper. His contribution to the debate was concerned with a tiny corner of the vineyard. He asserted that it was necessary to begin at the bottom, and he wished to leave with the members the suggestion that they should study wherever possible the value of the many little pebbles he had indicated, with which the partners in industry might fill up the chasm.

Mr. Henry M. Rounthwaite said that much of what he would have liked to say had already been dealt with by those who had taken part in the discussion. He desired to refer particularly, however, to Captain Savage's Communication which had been printed in the Proceedings (page 724). Captain Savage had suggested that much could be accomplished by propaganda. The only question that had to be discussed was therefore—what description of propaganda should be adopted ? The usual treatises on economics or political economy were not suitable. There was, for instance, a most excellent work written by Dr. P. H. Wicksteed—a brother of their former President, Mr. Hartley Wicksteed—which was, perhaps, one of the clearest and best, but it consisted of 700 pages

of very close argument. Many of the members could, no doubt, follow it, if they were willing to give time and patience, but it was often necessary to take half a page at a time and think carefully about it. Such material as that was not of direct value for propaganda.

Going back ninety years to 1832, when things in this country were very black, it occurred to Miss Martineau that if she could put the leading elementary facts of economics into the form of short tales or stories, they might be read where a heavier treatise would have no chance whatever. She was strongly dissuaded and met with much opposition; publishers would not take her material; but she persisted, and in 1831 published the first of her "Illustrations of Political Economy," and within a fortnight 5,000 copies had been sold. Not so many hand-workers could read in those days as at the present time, but she found a public—whether among working people or not it was impossible to say now, and the method was shown to be a good one by the fact that it "took on." Probably many similar attempts had been made since, but he remembered that that shrewd publicist, the late William T. Stead, had strongly advocated the story form for such purposes. Some of the members might have seen the articles by Major E. Stein, called "Wealth and Workers" in the *Cornhill Magazine* of the early part of the present year. In his opinion those articles were ideal in form, and they ought to be printed by the hundred thousand and distributed all over the country. Nothing could be better; they scarcely required a word of alteration.

It appeared then that what was required was that employers of labour should approach some well-known writers, men who were skilled in "the social essay," and pay them to write suitable material for propaganda. He thought that the Institution as a body could not spend money on such matters, as, apparently, the Memorandum and Articles of Association did not permit of that being done; so that the only hope was that opinions expressed at the Meeting might be of service to those who were employers of labour. He (the speaker) had prepared a rough draft of part of such a story as he had in mind, and would be pleased to send it to any employer who might feel interested in the idea.

Mr. W. Dent Priestman said the subject of the Paper appealed to him very much, and he proposed to make a few remarks with the object of showing what, in his opinion, the country needed, and if the members put him down as an optimist he could not help it. He had been greatly interested for the past fifty years in workmen, and had always had a strong belief that more was to be got out of most men if only touched in the right spot, and he therefore sympathized with the aim of the Institution in the endeavour to bridge the chasm to which reference had been made, for there was no doubt a great one existed at the present time. Stanley, when he came back from Africa, was taken to task because he expressed much pleasure in the pigmies. On being asked the reason, he replied: "You talk about beetles: why should I not talk about pigmies? The pigmy is surely a vastly more interesting piece of manufacture than the beetle."

He believed that 50 per cent or more of all the trouble that existed in regard to labour at the present day was because workmen were treated more as beetles than as human beings. If it was only possible to get out of the masters' heads: "You the labouring men are there, and we the employers are here," and if they would only say: "We need you and you need us," the chasm would be bridged very quickly, and it would be found that there was much more in men than the mere using of their hands for what they produced, and that they had as noble a part in the work as the employer, who, comparatively speaking, hardly ever saw them. How was that to be brought about? When he was a little lad California was the place looked to for gold; when he was a little older New South Wales became the goal, and subsequently South Africa and Klondyke. The gold miners expended much effort and underwent great hardships in order to extract gold out of the earth. Personally, he maintained that there was gold all round so far as the workers were concerned, which could be obtained without the pick or shovel. It was there if only proper means were used to win it. But how to do so was the difficulty!

When Mr. Hodge sent his requisition round in 1917 he told manufacturers that they must hurry up, and he desired to tell the

Meeting how Priestman Brothers acted, not because he wanted to eulogize on what they did, but simply as an illustration of what could be done. The whole of the members of the Hull Iron Trades Association were called together, and Priestmans asked: "Shall we all work together or shall we do as we think best?" When instructions were given to take the latter course, the reply was what his firm wanted. They called representatives of their men and said to them that if they would give the scheme an honest trial, the firm would give them 10 per cent on their base wage; if they produced 10 per cent or 20 per cent more output the 10 per cent would be added. The men said that to have money offered was too good to be true; it was like a brotherhood. A Shop Committee was formed, and the employers met the men every month and told them what the excess was over "the standard." At present they were getting something like 50 per cent more than the base wage for about 40 per cent increase in output in tons. Perhaps the excess for next month would be 50 per cent over what they were doing in pre-war days; and the employees would get the 10 per cent on that, so that they would receive 60 per cent over their base wage. That was the essence of Priestmans' scheme of co-operative production, and the firm had most friendly relations with their poeple. Personally, he did not often meet the men, but his eldest son, the works manager, and the secretary did so every month, and told them exactly what they had done and what they might look forward to. It was found, as a result of getting into close touch with them in that simple way, that friendly relationships existed, because they were satisfied with the return obtained for the extra work done. It had been said in connexion with the matter under discussion that "it seemed as if capital was pulling at one end of the rope and labour at the other," but at Priestmans capital and labour pulled at the same end. If he went into the shops on the following morning, he knew that the men would receive him with pleasure, which altered the whole tone of business. And what was being done at his works could be done elsewhere.

There was one thought he desired to put forward in closing, namely, that he believed it was fear on the part of employers

(Mr. W. Dent Priestman.)

that the men were determined to have a share in management which prevented the putting into operation of such systems; but from his experience he was of the opinion that if the men had confidence in their employers and obtained a reasonable return for the extra work turned out, they would leave the question of management with those who were trained for it.

Mr. E. Holden said he attended the Meeting as a supporter of his co-worker, the Author, who was one of the Directors of Messrs. Ruston and Hornsby. The keynote of the whole discussion could be summed up in one word, "co-operation." It was absolutely necessary that there should be straightforward co-operation. He wished to direct attention to two phases, the first of which had already been referred to, namely, the question of industrial welfare. He happened to be one of those individuals who could probably now be called "trouble removers," and during the past week he had had some peculiar experiences in that regard. He was trying to re-establish the human touch between the young workers in particular and the firm, trying to create that *esprit de* Firm which would of necessity not merely make them good men, but affect their line of conduct generally as citizens. To establish welfare work, a firm must do so as a definite principle of conduct and action in reference to the relations between the employer and the employed.

Welfare work was a plant of slow growth, and unfortunately in some instances it was unduly pressed. The Industrial Welfare Society, represented by Mr. Hyde, and the Society which he (the speaker) had the honour to represent, the Welfare Workers' Institute, would be quite happy to give helpful assistance at any time with regard to the founding of schemes. In that respect it might also be pointed out that definite action had been taken with regard to the training of officers for the work. Practically every University in the British Isles now had in operation, or very shortly would have, a scheme of training for welfare workers. Those schemes ran very nearly parallel to those for industrial administrators, because after all, welfare work was a function of management.

The other phase of the work to which he desired very briefly

to draw attention was that of education. He put forward the suggestion seriously that the Institution should consider what steps could be taken to help the needs of the younger engineers in the provinces. Young men in the neighbourhood of London had the privilege of attending Meetings which were frequently arranged at the Institution and other similar Societies, but the young engineer in the provinces was not in that fortunate position. Further than that, the new Education Act would introduce a new form of educational effort, in that, for the first time in the history of the British Isles, the young employee was about to learn the same language and to get a general outlook on life on similar lines to those of his employer. He would, if the new day continuation schools were properly administered, undoubtedly gain a wider outlook on life, which the employing classes naturally had had for generations, and he would get a different angle of vision generally with regard to work. He (the speaker) suggested that the Institution should support the ideals put forward in the Paper, and get the work of co-operation at once in hand.

Mr. J. E. Powell said the subject was one which had been of particular interest to him for quite a number of years. His duties had been very largely in connexion with the problem of obtaining output, and he presumed the members would agree with him that such duties were likely to bring one into contact with what might be described as the most human side of the human factor. He was not surprised that the discussion that evening had centred more or less round the question of payment by results. The object of industry was production, and linked up with that question of production was the important one of payment. Much was being said at the present time about systems of payment by results, collective, and individual. He did not propose to touch at all on the merits or demerits of either of those systems, but in the matter which was being both written and spoken, payment by results was being given the most important place, to the exclusion sometimes, he thought, of other aspects of the question which were of equal importance.

The Author stated in his Paper (page 710) : " Over a considerable

(Mr. J. E. Powell.)

period it"—the country—"became accustomed to a prodigal expenditure of wealth without particular scrutiny of the value received." He believed every word of that was true, but he asked the members to allow him to read the sentence slightly differently and to take them back to the pre-war situation, which he thought was very largely the cause of the present trouble regarding payment by results. He would read the sentence he had quoted in the following way: "The country was accustomed to expenditure of wealth without a sufficient scrutiny of the value received." He was as willing as anyone to admit that the worker was not producing all that he could. At the same time his experience, in connexion with the obtaining of output, had forced home, again and again, on him the fact that all the blame was not to be placed at the door of the worker.

The Author (page 713) insisted upon the necessity of a square deal; on page 715 the question was asked: "Has the inanimate side of production been reduced to the science it might become, or is industry still instinct with the conservatism of old-established practice? Is the art of production studied or does it simply evolve?" Again the statement was made on page 714: "There has been no real insistence on the fact that the primary duty at the moment is to produce in the utmost quantity at the cheapest rate." Bearing in mind the fact that in times past the relationship between employer and employed had been of a bargaining nature and had embodied on the part of the employer the lowest price for the greatest return, and on the part of the worker the highest reward for the smallest return (because, after all, that was the essence of bargaining), was it to be wondered at that the output obtained, not merely to-day but before the War, reflected that policy? He suggested that the present position was very largely the outcome of the policy which was followed in pre-war times, and that the country was suffering from that policy at the present time. The evidence, so far as he could read it to-day, was that that factor was not being sufficiently recognized, and, whatever might be the future policy, unless the reason underlying the existence of the present situation was recognized, it seemed to him to be possible that they would

be merely going round another of those vicious circles to which everybody had been so accustomed of late.

Dr. A. P. Thurston said he had wondered if it were not possible to bring into industry some of the spirit which had such a great effect during the War. What was it that constituted the leader of men ? During the War one saw fellows straining every nerve to serve a certain particular leader. No work was too great or too dangerous so long as they could serve that leader. At one time he wondered why that was so, until he overheard one of the men say : " All the time I have known So-and-so I never knew him say he was hot or cold, wet or ill, and I never knew him to forget anybody who was." It was the human element which in some way had such wonderful power over men. If it were possible to get men to feel and to know under all circumstances that there was a beneficent influence working with them, that life was a great sport, that everyone was in the hunt together, that neither one nor the other could take all the spoils, he thought in that way they would get down to the bottom of things. In looking back upon his past mistakes, the feeling came home to him that sometimes he had been engaged in a deep problem which had required his attention so much that he had not had the opportunity of explaining his position to his fellows, and therefore he had been misunderstood. Many failures had been due to the fact that a man did not take time to explain his position, what he was seeking, and what difficulties had to be solved. If the men could only be brought to realize what the difficulties were and the steps taken to overcome those difficulties, their whole-hearted support could be obtained. In connexion with the human element, he was certain it was important they should treat with the utmost courtesy and consideration all those engaged in the hunt, and then they would get labour " fully knocking with its hundred hands at the golden gate of the morning."

Mr. E. T. Elbourne said he had read with much interest not only the Paper, but the discussion that had previously taken place upon it, and, after hearing the further discussion that evening, he

(Mr. E. T. Elbourne.)

was deeply disappointed to find that, although the members of the Institution were responsible in their respective persons for management, so far very little had been said on that subject. It was most important, in his opinion, that consideration should be given to the three elements in production—finance, management, and labour—and unless they were properly conceived and understood the issue of the human factor would never be solved. Remembering the President's instruction to avoid any semblance of dealing with political matters, he would not touch on the situation that had arisen in connexion with the domination of Capital. In the management of a works, the manager was in a special position. He was the steward of capital, but he was also the director of labour, and he should hold the balance fairly between them. In his actions he should be the embodiment of equity. In a works of any size the duties of the manager made it impossible for him to have that personal contact with the workers without which no one could have sound foundations on which to build, and he must therefore delegate that duty to a considerable degree. He had learned the art of delegating the duties appertaining to technical production and discipline, but he did not seem to have equally learned the art of delegating the duty of personal contact with the men, and he must acquire it. The realization of personal contact was expressed by a better word than co-operation—namely, co-ordination. There ought to be a common direction of effort and a common outlook, and co-ordination would mean that result.

In speaking of co-ordination he wished to make one reference to practice; co-ordination had been established in both fact and name at Ponders End Shell Works during the War. There was a Works Co-ordination Committee and the Secretary of this Committee was also the Works Investigation Officer, though the speaker now preferred to use the term Labour Co-ordination Officer. He might even have been called "the Explanation Officer." This officer afforded a means by which each side was explained to the other. He suggested it was not "welfare," in the paternal sense advocated by some, that was required, but co-ordination founded on a common understanding of motives and methods. It was

necessary to explain themselves and to get explanations. Trouble arose out of misunderstanding. It had been well said, "More ill is done through want of thought than want of heart." Ignorance was the initial cause of many of the troubles that existed at the present time. It was necessary for each employer to get his own house put in order, and it was not reasonable for him to expect to obtain salvation by merely going, and still less by sending a delegate, to industrial conferences. It was occasion for serious reflection that their great Institution at present was exercising no influence on public opinion in regard to the vital issues concerned.

Mr. William H. Patchell (Member of Council) thought the Institution was to be congratulated on having faced so frankly the subject of the human factor. Some of the members were afraid of a Paper of the kind, because they thought it was outside the scope of a scientific Institution. Personally he did not hold that view. In his opinion if an engineer invented a machine to do certain work, it was within his province to see that that machine was worked to the best advantage. A machine might be held up by one of two causes: the workman might be weary or he might intentionally prevent the machine working. Mr. Henry Ford had in his works two cures for such maladies—the first medical, for cases which were due to fatigue; and the second surgical, for cases which were due to "cussedness."

The last night he (the speaker) was in New York he had the honour of attending the fortieth anniversary of the American Society of Mechanical Engineers, at which the speakers were Mr. Herbert Case, the Acting Governor of the Federal Reserve Bank of New York; Samuel Gompers, the President of the American Federation of Labour; and William B. Dickson. Mr. Gompers and Mr. Dickson might, he supposed, be considered poles asunder. The former he need not introduce; Mr. Dickson was the Vice-President of the Midvale Steel and Ordnance Company, but for all that, he pretty well "skinned" the Steel Corporation. In the course of his remarks Mr. Gompers said: "I see, however, before the labout movement a great future, as I also see a great future

(Mr. William H. Patchell.)

before the engineering profession, if the engineer should join hands with the workman—both devoting their energies to one cause—namely, the development of a kind of industry and a kind of work in which the man will not only learn the processes of production, but each day will have increasing opportunities to develop those human functions which are essentially intelligent." That was what we asked for in this country. They were entitled to expect goodwill and intelligent co-operation from each side. With regard to the political aspect of the meeting which had been mentioned, he would welcome more politicians at the Meetings of the Institution, because we desired to adopt every means in our power to make politicians engineers, to make them think and work accurately, but Heaven forbid that they should make engineers politicians!

Mr. Alexander Ramsay, in reply, said that in view of the lateness of the hour he would compress his remarks into a very few sentences. In his Paper and in his opening remarks at Lincoln, and on the present occasion, he was rather careful not to state any policy or any scheme to which he himself subscribed. He rather tried to state the problem. As a matter of fact there had been nothing proposed at the Meeting that evening to which he would not be willing to subscribe, and if time were available there were many other constructive proposals which he could have placed before the members. Colonel Carnegie rather took exception to the statement in the Paper that most of the great Trade Unions of the country had declared against working a system of payment by results. Colonel Carnegie took the line that they had declared, not against working the system, not against the principle, but against its operation; and he also denied that any security had been offered to the inefficient. He desired to suggest, with all respect, that if Colonel Carnegie had been making investigations into the industrial circumstances of this country, there was some indication that he had taken all his evidence from one side. He knew of agreements that had been made with regard to the question of payment by results on a national scale. The agreements provided that all prices should be fixed on such a basis as would

permit a man to earn 33⅓ per cent over his time wages, and every agreement which had been entered into provided that under no circumstances should a man earn less than his daily rate of wage. He ventured to suggest that that was security for the inefficient, and he really did not know what more ample security could be given.

Mr. Button, whom he was very delighted to see at the Meeting, made certain points which he appreciated very much. One was that the working man or the working lad in this country did not have the opportunity and the heritage to which he was entitled. Personally he was inclined to think that that was a general statement which went too far. In Scotland it was perfectly possible—and it was done in scores and hundreds of cases—for a boy of the humblest parentage to go right through school to the university and attain the very highest position, if he had the gifts. He ventured to think that if a lad, even of working parents, had that mental capacity and that depth he could make for himself a position, if he cared to do so. What one could not undertake to do was to create a uniform standard which was a top standard for everybody. There was a large measure of truth in that. He did not know whether it had ever struck the members that the mining communities, for example, lived a very isolated life. It would be found, in the great majority of cases, that a mining community had no dealings or connexion with any other industrial community. They lived together. The boys as soon as they left school went down the pit automatically and became miners, inheriting all their parents' traditions and outlook. That was a case in which the employing and the governing sections of the community could have done much more to develop the intelligence, the outlook and the sense of social responsibility than they had done. If one looked round, it was quite possible that many other instances might be found where similar action might have been taken with very beneficial results.

He was very glad to hear what Mr. Hyde had to say about welfare. Welfare, especially amongst young people, was one of the hopes of the industrial future. It was a real pleasure

(Mr. Alexander Ramsay.)

to him to see and hear Mr. Rounthwaite and Mr. Priestman. He had heard a great deal of their interest in the human problem and of the very human way in which they had handled it, with happy results, which he thought the members might do well to copy. All the discussion practically had centred round details, but he ventured to suggest to the Institution that there was one aspect of the question which was even more important—namely, in view of the fact that those who were responsible for developing the thought, the ideas and the programme for organized labour were distinctly joining issue with the employers on the principle of their organization, and were pressing for personal contact in the details of administration, it was of supreme importance that those who believed in the present system of organization should justify it, lest worse befall them. He concluded by thanking the Council for the invitation they extended to him to read the Paper before the Institution. It had been a very great privilege to do so, and he hoped it might have done some little good.

On the motion of the PRESIDENT, a very hearty vote of thanks was accorded to Mr. Ramsay.

Communication.

Mr. H. F. L. ORCUTT wrote that he felt very strongly that it was most important that the Institution should make a special effort to deal at the present time with subjects of this nature. He could not help thinking that, if they had taken this attitude many years ago, it would have been fruitful of good results. Why should the Institution confine itself to the discussion of purely technical or mechanical questions? The present situation was perfectly clear. England was now overstocked with mechanical equipment of the finest sort, plenty of machine-tools, instruments of precision, and fine buildings. He had recently been over a large works where

hundreds of the highest quality machine-tools were installed, dozens of them lying about not even taken out of their boxes, and plant not employed to one quarter of its capacity. This condition did not exist in previous years, but he would say now that the English were the equal of any nation in respect to mechanical equipment. At the same time it was admitted that our output per man was lower than it was previously; clearly the great subject presenting itself was "The Human Factor."

Engineering development, in which the Institution took so much interest, was absolutely blocked by the lack of assimilation of the human element necessary to operate the machines successfully. If the Institution did not take up these matters, it was a question if it did not do great harm by this neglect. Was it not possible that they were, by pushing to the front at this time purely technical matters, actually doing harm to their industries? Surely the engineer was in the best position to deal with the "human factor" in its relation to our mechanical problems. He was the only one with the knowledge and experience necessary to a solution of the difficulties.

Mr. Ramsay in his Paper mentioned particularly the workers' attitude as it affected output. What he said was quite true, but we were not gaining much by finding fault with each other, or trying to lay the blame on any one group or class. Was the working man on his job any bigger slacker, or did he show any more inefficiency than the employer did on his job? The effects of his moods on industry were more quickly seen because he was in greater numbers. Was he not moved by the same impulses to work or to play as the employer or the engineer? He either worked with the prospect of reward, because of his sense of duty, or because he was in want; so did every one. He wished that Mr. Ramsay had dealt more particularly with some of those questions which were pressing for an immediate answer. The most that could be done was to tackle those problems which seemed to be most important, and to work our way gradually to a state of better things.

To meet the demands of the hour, he would suggest that the Institution should consider, as one of the first moves, the appointment of what the American Society of Mechanical Engineers

called "Professional Sections." These Sections were working in the States very successfully. The most important problems which these Sections would have to face were easily discernible, amongst them unemployment, housing, and the training of men. Why should the engineer leave the training of boys to the Board School teachers, the housing of his employees to the slum landlord, unemployment to bureaucratic control (which he so fiercely denounced)? Would it not be well to appoint labour delegates as Members of the Council? They might impart a certain liveliness to the proceedings of the Institution.

The Institution of Mechanical Engineers.

PROCEEDINGS.

17th December 1920.

An Ordinary General Meeting was held at The Institution, London, on Friday, 17th December 1920, at Six o'clock p.m.; Captain H. Riall Sankey, C.B., C.B.E., R.E. (ret.), *President*, in the Chair.

The Minutes of the previous Meeting, held on 3rd December, were confirmed and signed.

The following Paper was read and discussed :—

"Thermodynamic Cycles in relation to the design and future development of Internal-Combustion Engines"; by William J. Walker, Ph.D., of the College of Technology, Manchester, *Associate Member*.

The Meeting terminated shortly after Half-Past Seven o'clock. The attendance was 130 Members and 33 Visitors.

The Paper by Dr. Walker was also discussed at :—

Manchester, in the Engineers' Club, on Thursday, 23rd December; Professor A. H. Gibson, D.Sc., *Member*, in the Chair.

THERMODYNAMIC CYCLES IN RELATION TO THE DESIGN AND FUTURE DEVELOPMENT OF INTERNAL-COMBUSTION ENGINES.

By WILLIAM J. WALKER, Ph.D.,
of the College of Technology, Manchester, *Associate Member.*

1. *Introduction.*—The notes comprised in the Paper to be given here represent an endeavour to place upon a practical working basis the application of thermodynamic theory to the science of internal-combustion engineering. This particular branch of engineering has, of recent years, outgrown most others, one might say, in the interest and fascination of its accompanying problems. It is hoped, therefore, that little apology is required for giving some attention to a discussion of the more or less theoretical aspects of the subject, both from the point of view of possible future development and from the standpoint of design.

The main portion of the Paper, embodying the result of perhaps much one-sided concentration, is based upon a fairly wide experience gained while carrying out tests on practically all kinds of internal-combustion engines, including those operated by coal-gas and producer-gas, oil-engines of the Diesel and so-called semi-Diesel

types, the hot-bulb oil-engine and also high-speed petrol-engines of the automotive class. It is but natural that constant association in this way with one particular branch of engineering should give rise to a gradual formation of ideas regarding the many and various questions which continually compel the attention of those engaged on such duties. Inevitably, perhaps, many controversial points are raised, but at the same time it is hoped that some order has been restored to a subject which suffers at present from some lack of co-ordination.

The outstanding feature in the thermodynamics of the internal-combustion engine, distinguishing it sharply from that associated with steam-engine practice, is the necessary inclusion of the *Variable Specific Heat Factor* in all fundamental analyses. Another point of difference (this opinion will probably be questioned) is that relatively little advantage is derivable from any application of the "Entropy" function to the discussion and elucidation of the phenomena involved. Accordingly no attention is given here to such application.

2. *Classification of Engine Types.*—Some classification of the various existing and proposed types of engine will be attempted first, in order to prepare the way for the subsequent portions of the Paper. Classification of some kind, of course, is necessary in any subject which is to be studied with any presumption to scientific method. At the present time, owing to the somewhat chaotic state of internal-combustion engineering nomenclature, this classification has become a matter of no little difficulty. Such terms as "cycles of operation," "methods of operation," semi-Diesel, etc., are used with little or no definite meaning. Terms on a par with the last given are often employed in describing some particular type of engine, but any indication of the *principles* on which the engine is operated will be looked for in vain in the particular term used. This confusion, arising as it has, out of the prevailing multiplicity of engine types, may not cause much inconvenience to those engineers well versed in modern practice. At the same time, however, it has been the Author's experience that to have an

orderly and at the same time thorough grasp of the subject, some classification is very necessary other than those of the usual text book origin, which by their incompleteness give rise to doubt and misconception regarding the correct definition to be applied to some comparatively recent type of engine. The classification about to be described here will, it is hoped, be found comprehensive enough to include all existing or probable types. Briefly, it is based upon the three most important factors affecting the running of an internal-combustion engine, namely:—

(1) *The Method of Ignition* employed to initiate combustion. This more or less determines *the combustion efficiency* of the engine.

(2) *The Method of Operation* employed to carry out the thermodynamic cycle of the engine. This more or less determines *the mechanical and volumetric efficiencies* of the engine.

(3). *The Thermodynamic Cycle* to which the working fluid is subjected. This more or less determines *the thermal efficiency* of the engine.

The first distinguishing factor, the *Method of Ignition*, may be classed under four heads, according as the combustion is initiated by—

(*a*) Surface Combustion.
(*b*) Electric Spark.
(*c*) High Compression.
(*d*) Flame Injection.

It is interesting to note that (*a*) includes the earliest and also one of the latest methods of ignition, namely, the hot incandescent tube of early gas-engine days, and now the well-known "hot-bulb" of a type of oil-engine which has come recently into favour for certain classes of work; (*b*) requires no comment, and (*c*) is, of course, the achievement of Diesel; (*d*) represents a method of ignition which has had little serious development, but it possesses an interest of its own to which reference will be made later.

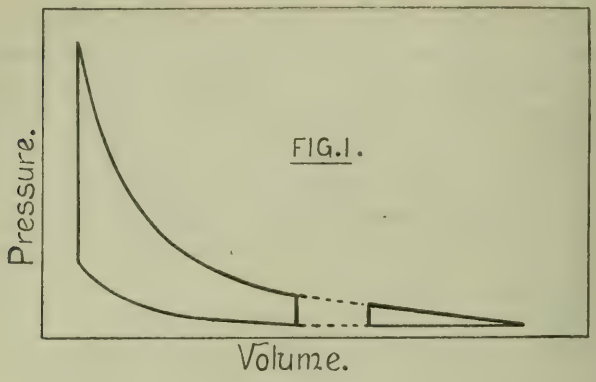


FIG. 1.

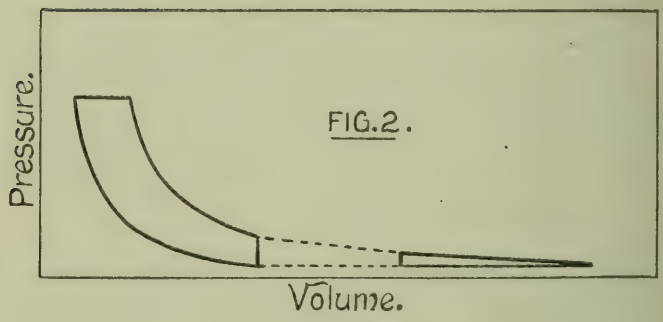


FIG. 2.

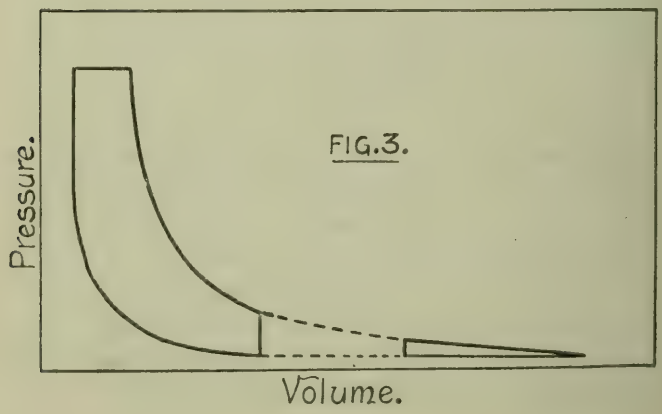


FIG. 3.

The Method of Operation given as the second distinguishing factor, includes only the two well known four-stroke and two-stroke methods. The probability of others displacing these appears at the present time very remote.

Figs. 1 to 3 have been drawn to illustrate the classes into which the third distinguishing factor, the *Thermodynamic Cycle*, may be divided. Thus in Fig. 1, the full line diagram to the left represents the Constant Volume Combustion Cycle (C.V. Cycle) with Compression Volume Expansion. This is the standard cycle for most modern engines. With the dotted portion of the diagram included in the full line left hand portion, the figure represents the C.V. Cycle with Extended Expansion. So far as the Author is aware there are no engines in existence operating on this cycle at full load. The entire diagram represents the C.V. Cycle with Complete Expansion. This is the cycle of the well-known Atkinson engine and also of the Humphrey Pump.

Similarly Fig. 2 represents the Constant Pressure Combustion Cycle (C.P. Cycle) with the same three divisions according to expansion. The first division represents the Diesel engine cycle, the second has no counterpart in past or existing practice, while the third is typified by the Brayton gas-engine cycle.

Fig. 3 represents the class of cycle on which engines, such as the Blackstone oil-engine, are operated, and is here called the Dual Combustion Cycle * (D.C. Cycle), the heat being imparted, some at constant volume and the remainder at constant pressure. This cycle is also divisible as before into three sections according to degree of expansion.

It is interesting at this stage to turn the attention to an experimental engine of Sir Dugald Clerk's † which was certainly the first, giving a very close approximation, at least, to the dual combustion type of cycle. High compression was not used, the problem apparently being approached in a similar manner to that followed in a well-known and comparatively recent method of

* *The Automobile Engineer*, January 1918. Paper on "Thermodynamic Cycles."

† "The Gas, Petrol, and Oil Engine," Clerk and Burls, vol. ii, pages 261-9.

initiating combustion in Diesel engines employing heavy tar-oils as fuel. In this method a small quantity of light spirit is injected for the purpose of producing a slight explosion or combustion at constant volume, thus raising the temperature of the working fluid to the additional degree necessary to burn, at constant pressure, the heavy tar-oil injected later. In the Clerk engine air only was compressed as in the Diesel engine, but the compression being low the temperature was not sufficient to initiate combustion when the compressed gas was injected, so a flame-jet was used, this flame-jet performing the function of the small quantity of light spirit in the type of Diesel engine already considered. This was the first successful attempt to employ the flame-injection method of ignition.

Other engines which are operated approximately on the dual-combustion principle are the Sabathé engine, the De La Vergne engine, and the Trinkler-Körting engine. *

3. *Combustion Processes.*—It is well at this juncture to define certain quantities involved in the different cycles, particularly those quantities relating to the combustion processes. Since the combustion processes, in which present-day engineers are almost wholly interested, are those taking place either at constant volume or at constant pressure, it will be convenient to refer to those processes here in terms of two quantities which are defined as follows :—

(1) The ratio of the pressure at the end to the pressure at the beginning of constant volume combustion. This ratio is denoted by α.

(2) The ratio of the volume at the end to the volume at the beginning of constant pressure combustion. This ratio is denoted by ρ.

A misconception † to which attention may be drawn here is the

* Proceedings, Am. Soc. M.E., 1911.

† *Internal Combustion Engineering*, 1914, page 286.

impression that the efficiency of the constant pressure combustion cycle is, theoretically, adversely affected by the addition of heat at constant volume, as for instance, when a small quantity of oil burned at constant volume is used to facilitate the combustion of heavy tar-oils. The formula for the efficiency of the D.C. Cycle

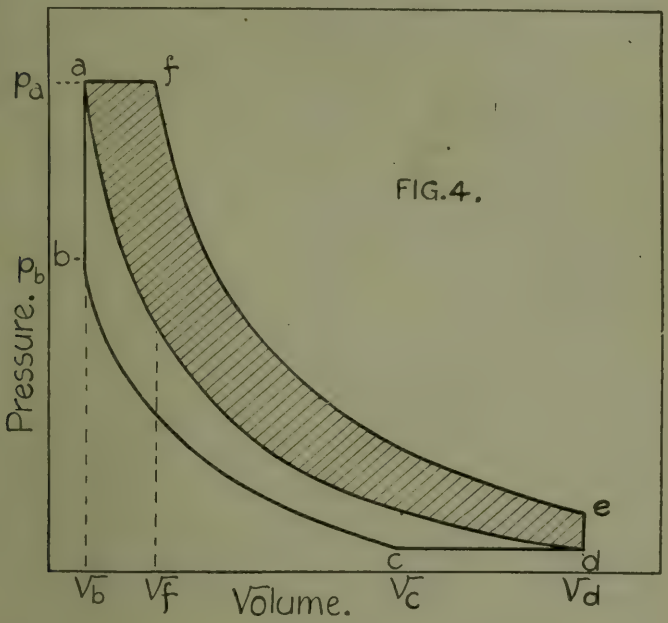


FIG. 4.

with suction volume expansion, assuming constant specific heat, can be shown to be *

$$\eta_d = 1 - \frac{1}{r^{\gamma-1}} \left\{ \frac{\alpha \rho^{\gamma} - 1}{\alpha - 1 + \gamma \alpha (\rho - 1)} \right\} \quad . \quad . \quad . \quad . \quad (1)$$

where r = compression ratio

and γ = ratio of $\frac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}}$.

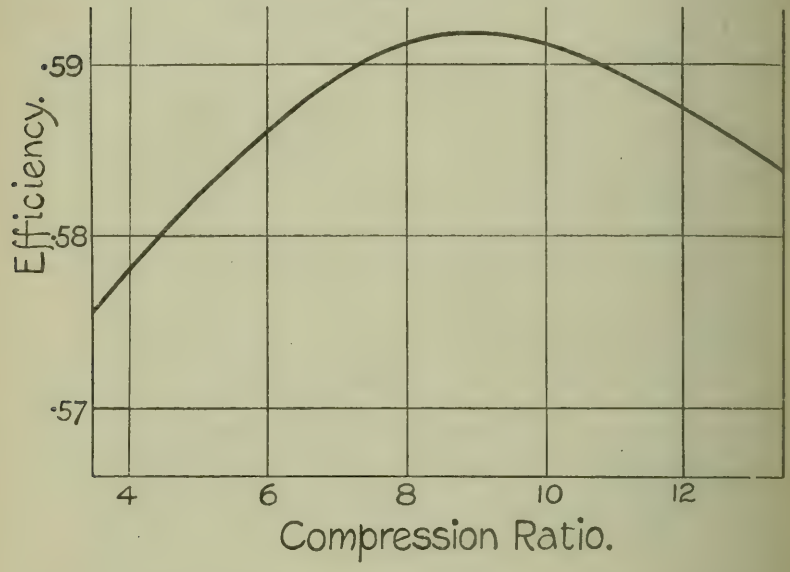
If the curves are plotted by means of (1) showing the variation

* *The Automobile Engineer*, January 1918.

of efficiency η_d with a, it is readily apparent that the efficiency increases with a, when r and ρ are constant.

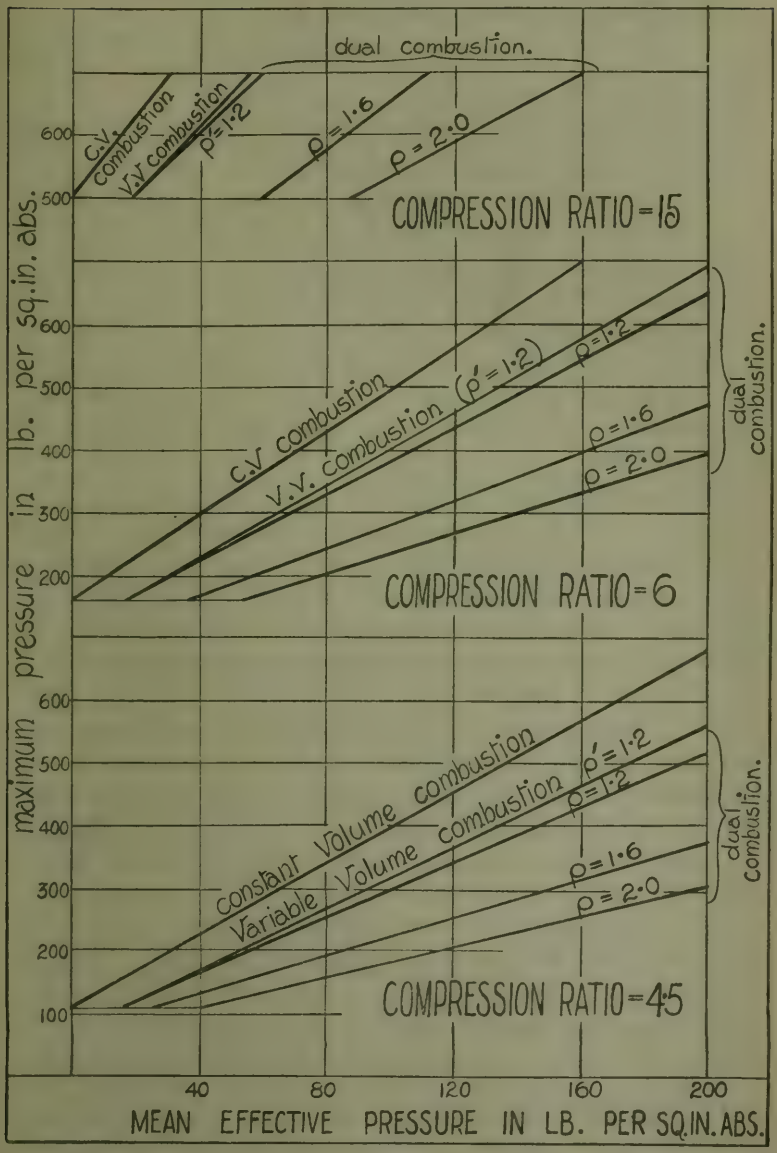
The point may be raised, of course (and generally is), that the basis of equal compression ratios is not a fair one for purposes of comparison. It is justly claimed that the basis should be that of equal maximum pressures. Even conceding this, however, it does

Fig. 5.



not appear that there is any reason to condemn the introduction of additional combustion at constant volume into a cycle in which fuel is burned at constant pressure. Thus, in Fig. 4, the shaded area $a\,d\,e\,f$ represents a normal Diesel engine diagram. This is compared with the complete figure $a\,b\,c\,d\,e\,f$ representing another cycle of the same maximum pressure, but with a lower final compression pressure, combustion being initially carried out at constant volume to give an explosion pressure equal to the final compression pressure of the first cycle. It should be observed that this second cycle is the *D.C. Cycle with extended expansion.* The efficiency expression for this has also been obtained and is given

FIG. 6.


dual combustion.
C.V. combustion
V.V combustion
ρ'=1·2
ρ=1·6
ρ=2·0
COMPRESSION RATIO=15
C.V combustion
V.V. combustion (ρ'=1·2)
ρ=1·2
ρ=1·6
ρ=2·0
dual combustion.
COMPRESSION RATIO=6
constant Volume combustion
Variable Volume combustion
ρ'=1·2
ρ=1·2
ρ=1·6
ρ=2·0
dual combustion.
COMPRESSION RATIO=4·5
maximum pressure in lb. per sq.in. abs.
100
200
300
400
500
600
40
80
120
160
200
MEAN EFFECTIVE PRESSURE IN LB. PER SQ.IN. ABS.

in another Paper.* It is sufficient to state here that the maximum efficiency condition of the cycle is given by

$$(\gamma - 1)\, r^{\gamma} - A\, r^{\gamma-1} + B = 0 \quad . \quad . \quad . \quad . \quad (2)$$

where A and B are constants.

Assuming that the maximum pressure is determined by $r = 13$ in the true Diesel Cycle, the compression ratio giving maximum efficiency is found by means of (2) to be somewhere about 9 when $\rho = 2$. This gives a value of α of 1·7. The variation of efficiency with compression ratio is given in this case by Fig. 5, where the maximum point is evident. Also, the higher the value of ρ, the lower is the compression ratio giving maximum efficiency. It thus appears that the efficiency of Diesel engines may be increased by *diminishing* the compression ratio and introducing additional combustion of fuel at constant volume as in the extended expansion cycle of Fig. 6.

It is claimed, however, on behalf of the Diesel Cycle, that its high efficiency is in some measure due to the fact that the quantity of air necessary for the combustion of the fuel injected at maximum load is always appreciably less than that actually present in the cylinder. The claim certainly has some truth in it, but nevertheless has nothing to do with any really inherent advantage to be derived from the use of so-called weak mixtures. It is well known that the fundamental theory of the Diesel Cycle shows that high efficiencies are to be realized with small values of ρ, and that if the mixture is to be strengthened (that is, if ρ is to be increased) the efficiency of the cycle must suffer. That fact, however, is no proof that richer mixtures may not be thermodynamically advantageous for use in other cycles. It is evident, of course, that in the D.C. Cycle of Fig. 4 (page 1241) a richer mixture must be used than in the corresponding Diesel Cycle shown. Were it desired, however, to burn the same quantity of fuel per lb. of air in the Diesel Cycle as in the D.C. Cycle, the efficiency of the former would suffer to an extent which would render it very much

* "A New Thermodynamic Cycle," *Engineering*, 109, page 467, 9th April 1920.

further at a disadvantage in comparison with the efficiency of the D.C. Cycle. Flame temperatures will be higher in the D.C. Cycle, but the extent of these does not appear to offer any insurmountable difficulties in the way of the adoption of the cycle. There are, besides, well-known methods of keeping down flame temperatures.

It may be considered that all that has been done in evolving this cycle is to continue further the expansion of the original D.C. Cycle with compression volume expansion. This has already been suggested and carried out by several inventors, notably Atkinson, with the object of increasing the efficiency of the Otto or C.V. type of engine. That the efficiency would be increased is obvious, but the point to be noted is that either constant volume combustion or constant pressure combustion alone do not yield a maximum efficiency cycle at a medium compression ratio such as is given by the dual combustion method. The reason why such additional expansion has received little serious attention is due to the appreciable diminution in mean affective pressure which accompanies its adoption in the C.V. and C.P. Cycles. This objection does not hold to the same extent in the D.C. Cycle.

The high compression of the Diesel Cycle is the main objection to its use for automobile and aero engines. The D.C. Cycle offers a method of obtaining high efficiencies without the excessive compression ratios of the Diesel engine.

4. *Variable Specific Heat.*—The question as to how much of the variability of specific heat is apparent and how much is real does not greatly matter for present purposes. Some is probably due to real variable specific heat, some to cooling, a little to after-burning, and still less to dissociation. The experimental values available do not agree very well amongst themselves. The tendency at first was to look upon specific heat as varying directly with temperature. Later the B.A. Committee on Gaseous Explosions recommended that a term involving the square of the temperature be included. Values due to Pier and Bjerrum,* are, however, now available

* *Zeit fur Elektrochem*, 1909, vol. xv, page 536; 1910, vol. xvi, page 897; 1911, vol. xvii, page 731; 1912, vol. xviii, page 101. *Zeit fur Phys. Chem.*, 1912, vol. lxxix. See also *The Automobile Engineer*, February 1920, page 57.

which throw considerable doubt upon the validity of the assumption that the temperature-squared term possesses any great importance. The internal energy curves deduced from Pier and Bjerrum's figures have very much less curvature at temperatures over 3,000° C. than those of the late Prof. Hopkinson's as deduced from B.A. values for specific heat. It is considered that for all practical purposes it is sufficient to formulate the closely approximate law that "*the 'apparent' specific heat varies directly with temperature.*" This assumption is in close agreement with the facts as given above. The inclusion of another term involving the square of the temperature is probably quite unnecessary for practical purposes.

The value of the factor which gives the rate of change of specific heat with temperature is obviously one which can be determined only by reference to the results of engine and explosion vessel tests.

In this connexion it is important to inquire briefly into the effect of engine speed and conductivity of cylinder walls upon this apparent specific heat factor by noting their effect upon engine efficiency.

As recent experiments have shown, both on air-cooled and water-cooled engines of the high-speed type, the actual thermal efficiency on brake horse-power lies, for all good designs, somewhere between 25 and 35 per cent with compression ratios varying from 4·5 to 6. This compares well with the efficiency of the stationary slow speed gas- or oil-engine, and indicates that so far as thermal efficiency is concerned, the speeds of operation so far employed have little or no effect, provided that the engine is designed to give good volumetric and mechanical efficiencies. The independence of brake thermal efficiency upon speed has been very clearly demonstrated by this high-speed petrol-engine experimental work. There seems to be but slight departure from accuracy, therefore, in stating that —the brake thermal efficiencies actually realized, approach, according to perfection of design, to a theoretical maximum, which is indentical for all types of engine operating on the same thermodynamic cycle, and is independent of engine speed.

In the case of the conductivity of the cylinder walls it has

been found that the effect of low conductivity or bad cooling is to diminish the thermal efficiency on brake horse-power. This is clearly brought out in comparing tests of air-cooled engines with cast-iron and aluminium cylinders respectively. In every case, however, investigation shows that this diminution in brake thermal efficiency is due wholly to a diminished volumetric efficiency. When allowance is made for this diminution in volumetric efficiency, both the indicated and brake thermal efficiencies of both types are found to be practically identical. Hence it may be enunciated that—provided that the conductivity or the effectiveness of the cooling system does not affect the volumetric efficiency to any appreciable extent, its effect upon brake thermal efficiency is negligible.

According to the usual notation, the formulæ expressing the relationship between specific heat and temperature are generally given as follows:—

$$K_p = A + ST + S'T^2$$
$$K_v = B + ST + S'T^2$$

where A, B, S and S′ are constants and T is absolute temperature

The ratios $\frac{S}{B}$ and $\frac{S'}{B}$ will be denoted by the symbols λ and λ'.

The numerical value in foot-lb. units adopted by the Author for the constants in the above formula, as conforming closely to generally accepted engine and explosion vessel tests, are as follows:—

$K_p = 317 + 0{\cdot}0623$ T foot-lb. per lb. per ° C. . . (3)
$K_v = 220 + 0{\cdot}0623$ T „ „ „ . . (4)

s' being considered negligible.

From (4)

$$\lambda = 0{\cdot}000283.$$

The acceptance of such figures can only be claimed on their agreement with values already obtained in engine tests, and this agreement appears to be, in general, fairly close.

The following formula has been obtained by an extension of an analysis* already given in another paper. If η' represents the theoretical thermal efficiency of any of the different classes of C.V.

* *Philosophical Magazine*, September 1917.

C.P., and D.C., cycles, then the indicated thermal efficiency to be expected from engines in practical operation will be given in each case to a first and close approximation by

$$\eta = \eta' \left\{ 1 - \left(\frac{\lambda' T_a^2}{2} + \lambda T_a \right) \left(\frac{\alpha + \rho}{2} \right) \right\} \quad . \quad . \quad . \quad . \quad (5)$$

where $T\alpha$ = initial compression temperature in ° C. abs.

The expression in double brackets represents the "diminishing factor" due to the action of the "apparent" variability of specific heat, η' being the efficiency of the cycle under constant specific heat conditions.

5. *Relations between the Mean Effective Pressures, the Maximum Pressures and the Efficiencies of the Various Cycles.*—The variable specific heat expressions giving the relations between the mean effective pressures, the maximum pressures and the efficiencies are somewhat lengthy, and for that reason are not stated here.

Figs. 6 to 10 have been plotted by means of the formulæ thus derived, giving the relationship between the most important quantities with which engineers, specializing in internal-combustion work, are intimately concerned. The graphs given there have been subjected to a good deal of practical application, and have been found to approach as near to the truth as it would appear to be possible to arrive in any theoretical treatment of the subject.

Referring to Fig. 6 (page 1243), it will be observed that five different cycles are concerned, all of the incomplete expansion type of present-day practice. The first is the usual C.V. Cycle. The second is what may be called a *Variable Volume Cycle* (V.V. Cycle) and is represented by such a diagram as is given in Fig. 12 (page 1256), in which the combustion line, instead of being vertical, leans over somewhat to the right as shown there. Here some further explanation is necessary. The symbol ρ' in this cycle chosen as 1·2 in the example given, is the ratio:—

$$\frac{\text{Volume at end of combustion}}{\text{Volume at beginning of combustion}}.$$

The third, fourth, and fifth cycles are of the dual combustion type with $\rho = 1{\cdot}2$, $1{\cdot}6$, and 2 respectively.

It is interesting to observe from Fig. 6 how the maximum pressure of a cycle is diminished for the same mean effective pressure when the constant volume combustion process is slightly departed from to give a value of 1·2 for ρ' in the V.V. Cycle. Fig. 9 (page 1252) shows also that for this degree of departure from the standard C.V. Cycle, the V.V. Cycle actually has a higher efficiency under certain circumstances. This result is surprising but close investigation into the matter has failed to indicate any error in the analysis or the calculations involved. The main reason for this was then seen to lie in the lower maximum temperature of combustion in the cycle with the sloping combustion line, so that the loss (according to constant specific heat theory) due to departure from constant volume combustion conditions is more or less counterbalanced by the diminution of the loss due to the variable specific heat.

Fig. 7 (page 1250) gives the relationship between the mean effective pressures and compression ratios of all the cycles, when the maximum pressures are respectively 300, 400, and 500 lb. per square inch abs.

Fig. 8 shows, for different compression ratios, the variation in m.e.p. with the cut-off ratio ρ of the D.C. Cycle. It is interesting to observe here, how much more rapidly the mean effective pressures increase with ρ at a low compression ratio than a high one.

Fig. 9, showing the relationship between thermal efficiency and mean effective pressure is a most instructive diagram. It shows that:—

1. The higher the compression ratio the more is constant volume combustion at a disadvantage compared with variable volume combustion. Thus, at a compression ratio of 15, efficiencies for C.V. Cycles having mean effective pressures greater than 60 lb. per square inch, are less than the efficiencies of V.V. Cycles of the same mean effective pressure.

2. The efficiency of the D.C. Cycle with $\rho = 1 \cdot 2$ is, for mean effective pressures above 60 lb. per square inch, always greater than the efficiency of the C.V. Cycle.

FIG. 7.

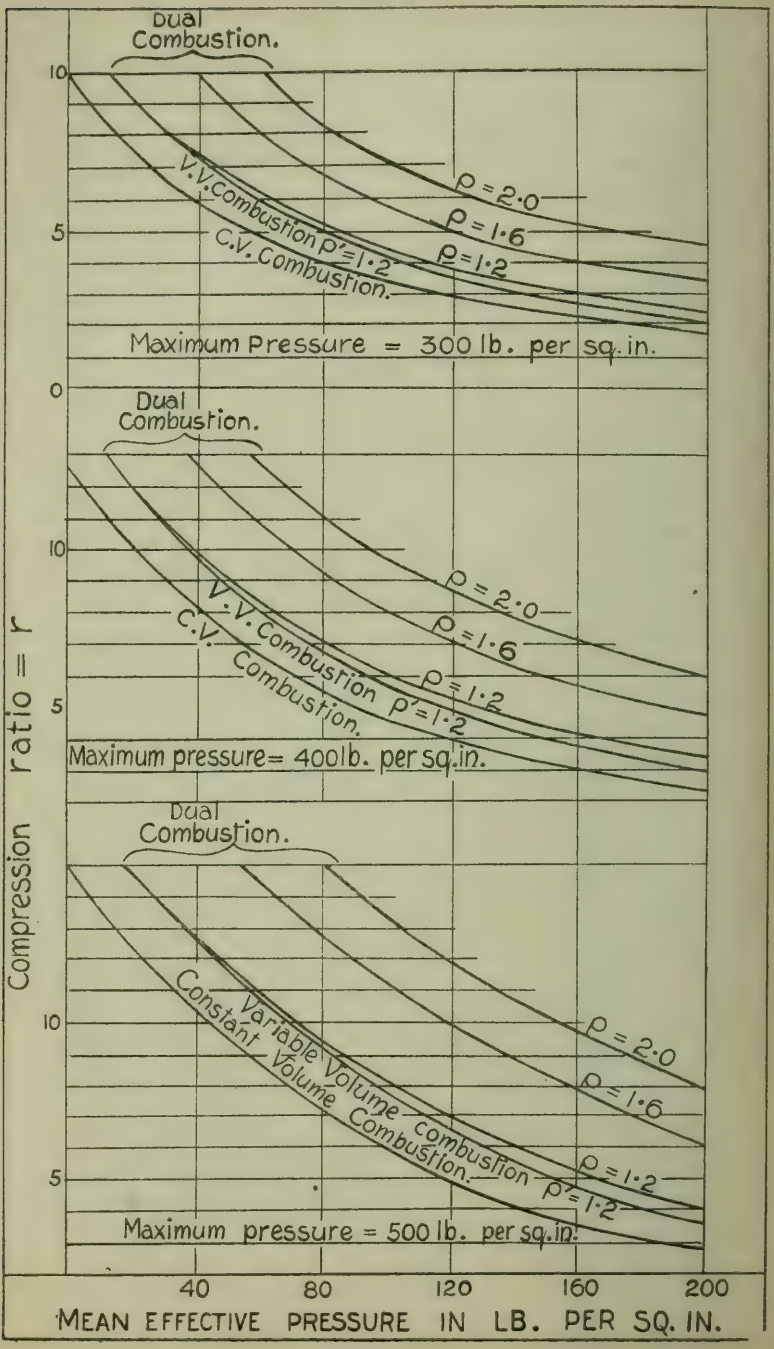

Dual Combustion.
V.V. Combustion ρ'=1·2
C.V. Combustion.
ρ=2·0
ρ=1·6
ρ=1·2
Maximum Pressure = 300 lb. per sq. in.
Dual Combustion.
V.V. Combustion ρ'=1·2
C.V. Combustion.
ρ=2·0
ρ=1·6
ρ=1·2
Maximum pressure= 400 lb. per sq. in.
Dual Combustion.
Variable Volume Combustion ρ'=1·2
Constant Volume Combustion.
ρ=2·0
ρ=1·6
ρ=1·2
Maximum pressure = 500 lb. per sq. in.
Compression ratio = r
10
5
0
10
5
10
5
40
80
120
160
200
MEAN EFFECTIVE PRESSURE IN LB. PER SQ. IN.

Fig. 8.

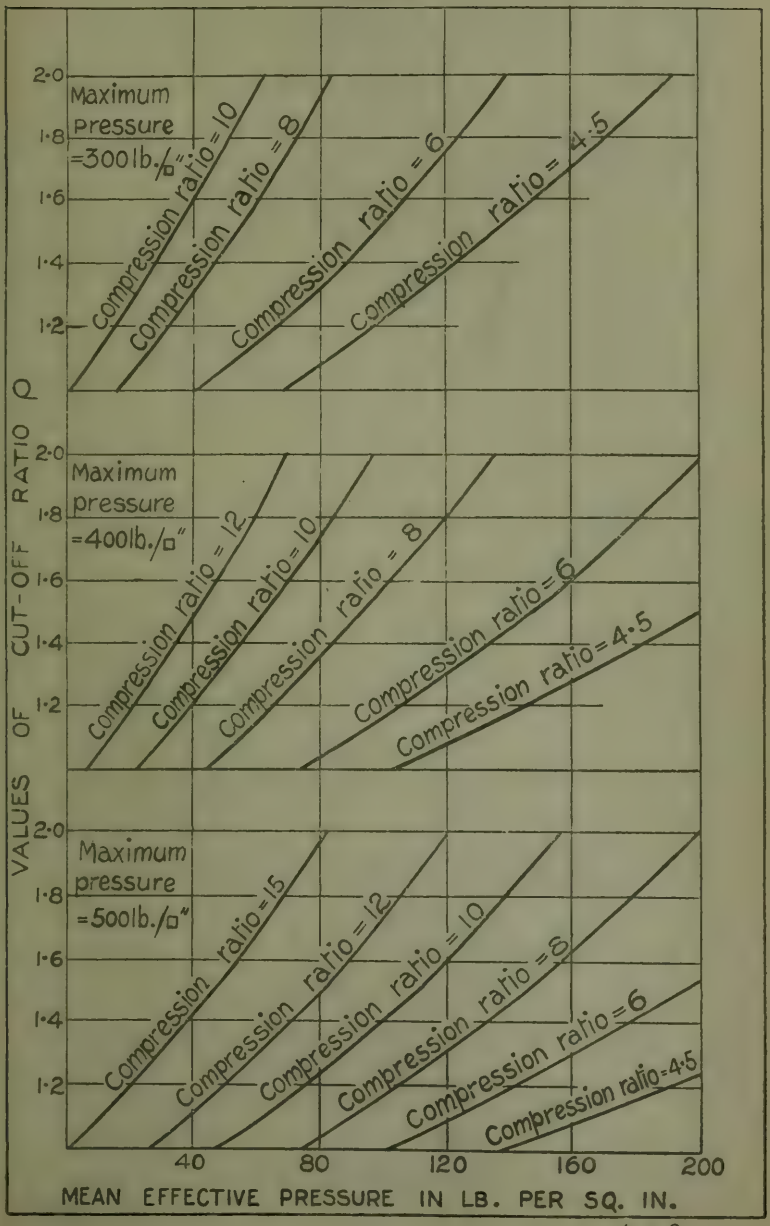
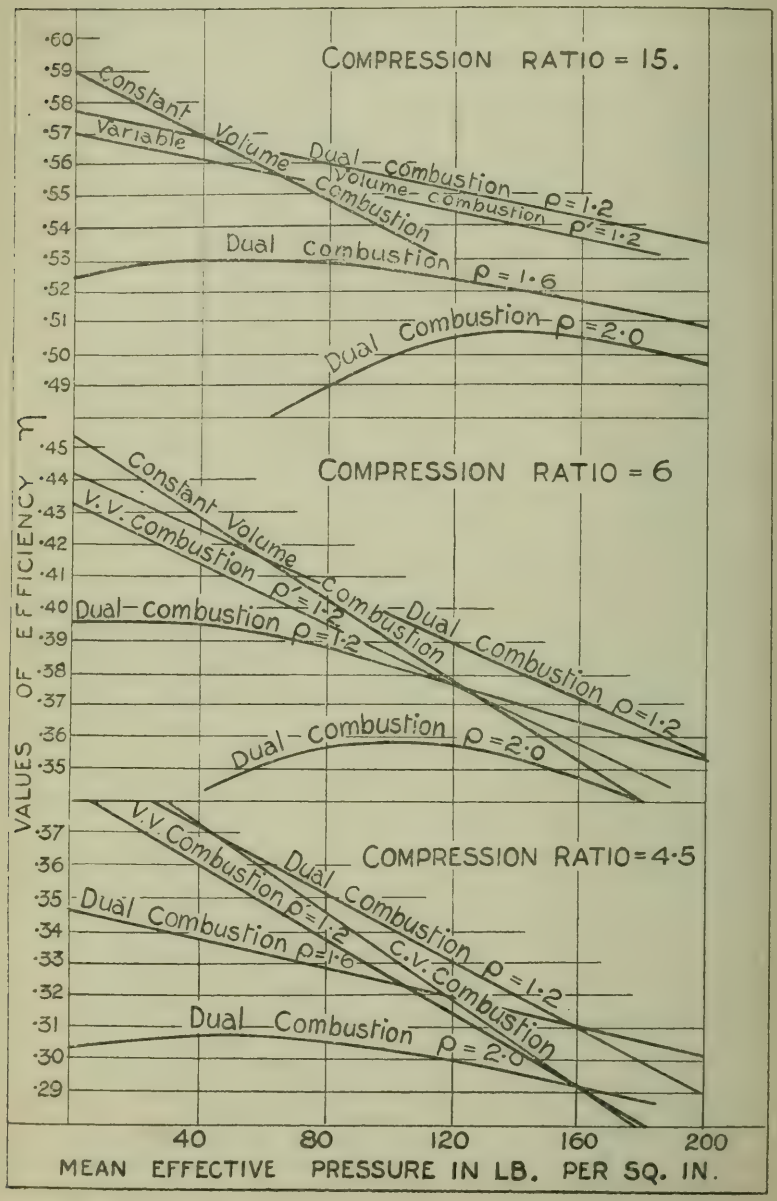
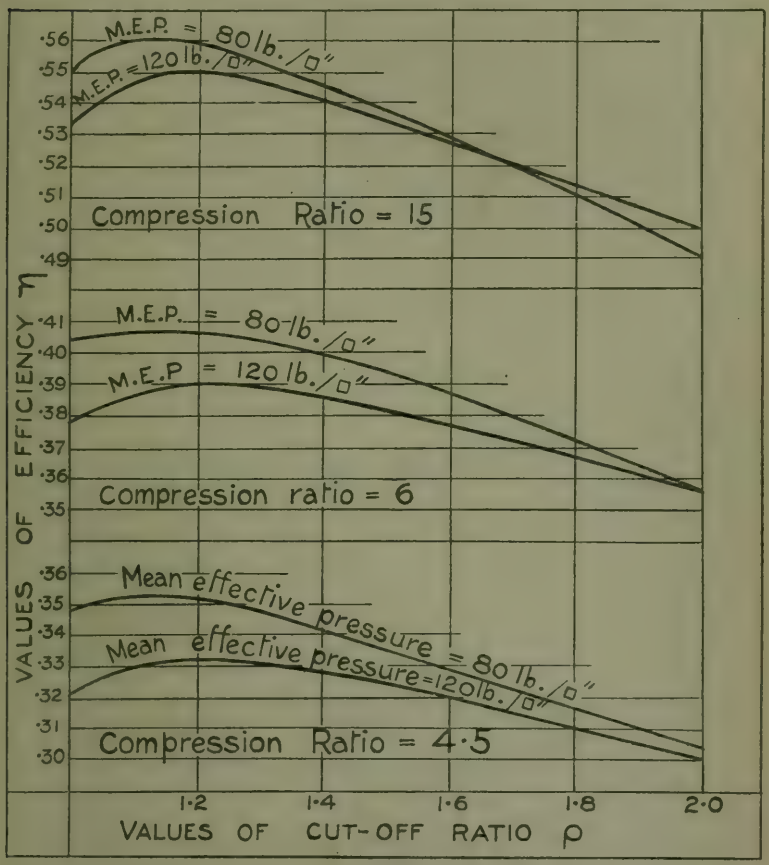

Maximum pressure =300lb./□"
Compression ratio = 10
Compression ratio = 8
Compression ratio = 6
Compression ratio = 4·5
Maximum pressure =400lb./□"
Compression ratio = 12
Compression ratio = 10
Compression ratio = 8
Compression ratio = 6
Compression ratio = 4·5
Maximum pressure =500lb./□"
Compression ratio = 15
Compression ratio = 12
Compression ratio = 10
Compression ratio = 8
Compression ratio = 6
Compression ratio = 4·5
VALUES OF CUT-OFF RATIO ρ
2·0
1·8
1·6
1·4
1·2
40
80
120
160
200
MEAN EFFECTIVE PRESSURE IN LB. PER SQ. IN.

FIG. 9.


COMPRESSION RATIO = 15.
Constant Volume
Variable Volume
Dual—combustion ρ = 1·2
Volume-combustion ρ' = 1·2
Dual combustion ρ = 1·6
Dual combustion ρ = 2·0
COMPRESSION RATIO = 6
Constant Volume Combustion
V.V. combustion ρ' = 1·2
Dual—combustion ρ = 1·2
Dual Combustion ρ = 1·2
Dual—combustion ρ = 2·0
COMPRESSION RATIO = 4·5
V.V. Combustion ρ' = 1·2
Dual Combustion ρ = 1·2
Dual Combustion ρ = 1·6
C.V. Combustion
Dual Combustion ρ = 2·0
VALUES OF EFFICIENCY η
·60 ·59 ·58 ·57 ·56 ·55 ·54 ·53 ·52 ·51 ·50 ·49
·45 ·44 ·43 ·42 ·41 ·40 ·39 ·38 ·37 ·36 ·35
·37 ·36 ·35 ·34 ·33 ·32 ·31 ·30 ·29
40 80 120 160 200
MEAN EFFECTIVE PRESSURE IN LB. PER SQ. IN.

3. The diminution in efficiency with mean effective pressure becomes less as the value of ρ in the D.C. Cycle increases and, if the value of ρ is great enough, may even show an increase with increase

FIG. 10.



of mean effective pressure, as appears in the Fig. in the cases when $\rho = 2$.

Fig. 10, which shows the relationship between efficiency and cut-off ratio, indicates at a glance that maximum efficiency in all cases is in the neighbourhood of $\rho = 1 \cdot 2$.

Fig. 11 is a diagram which is given here in the hope that, in conjunction with Figs. 6 to 10, it will prove serviceable to those engaged in the design and testing of internal-combustion engines. The assumption made in the construction of this diagram is, that 1 lb. of the working fluid occupies 18 cubic feet at 373° C. abs. and 14·0 lb. per square inch, and it is further assumed that this is the state of the mixture at the beginning of compression in any hypothetical engine. Conditions certainly do not vary widely from this in normal cases working at full load. At the foot of the diagram the lines of quasi-hyperbolic shape and the straight lines radiating from the origin represent the adiabatic pressure-volume and general pressure-temperature relationships for the fluid under variable specific heat conditions. The intrinsic energy curve of the gas and the constant pressure energy line are both plotted against temperature.

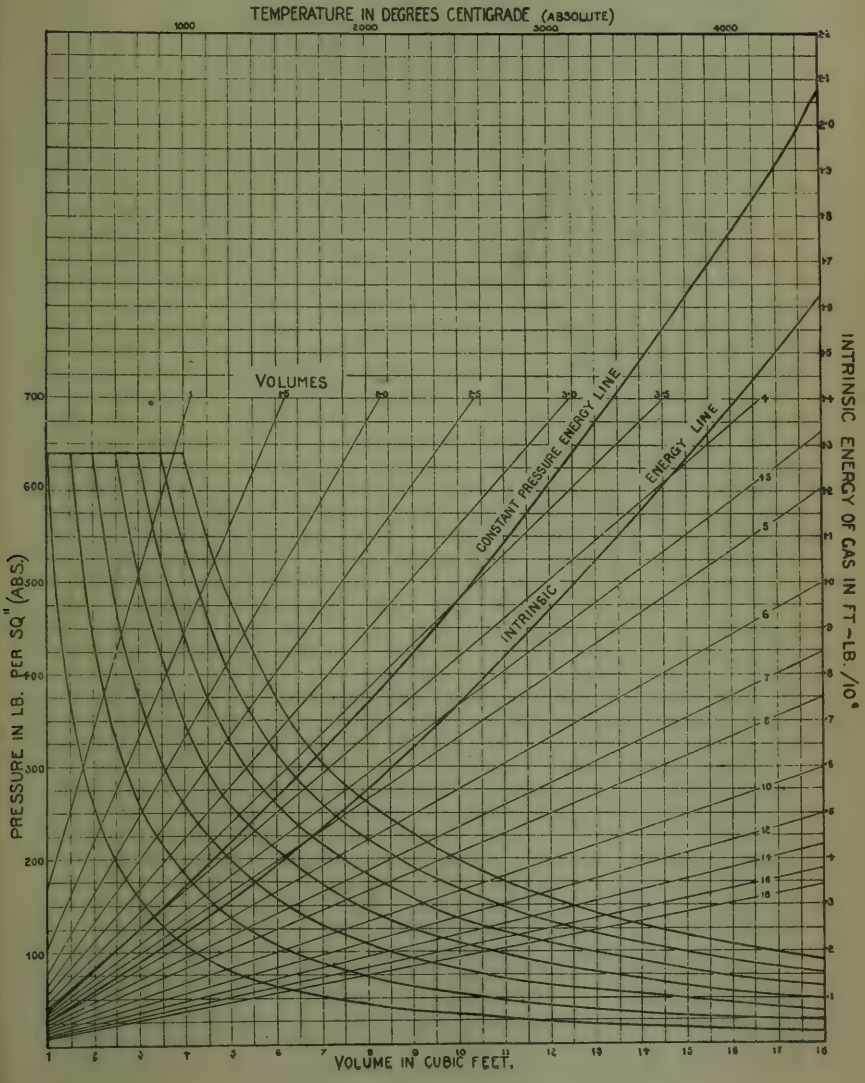
Given the compression ratio and the heating value of the mixture to be used in the engine, it is possible to obtain from Fig. 11, with reasonable accuracy, the diagram to be expected in any hypothetical cycle which is being considered for purposes of engine design. Conversely, given the actual diagram from an engine, it is possible, by superposition of that diagram to the correct scale and in its correct position in Fig. 11, to determine readily the working temperature, etc., at any point in the cycle. The use of the diagram is best illustrated by describing specific examples.

The first example is illustrative of high-speed aero engines using petrol. It is assumed that the theoretically correct mixture strength, corresponding to a normal air/petrol ratio is equivalent to a heat supply of $0{\cdot}81 \times 10^6$ foot-lb. per lb. of cylinder contents. Following the lowest pv curve, it is determined that when 1 lb. of gas is compressed from 18 cubic feet to 4 cubic feet (that is, a compression ratio of 4·5, common to air-cooled aero engines) the final pressure is 107·5 lb. per square inch abs. Striking across horizontally from this to meet the radial $p\mathrm{T}$ line representing a volume of 4 cubic feet, it is found that the temperature on the scale given is 650° C. abs., corresponding to an intrinsic energy of

FIG. 11.—*Internal-Combustion Engine.*

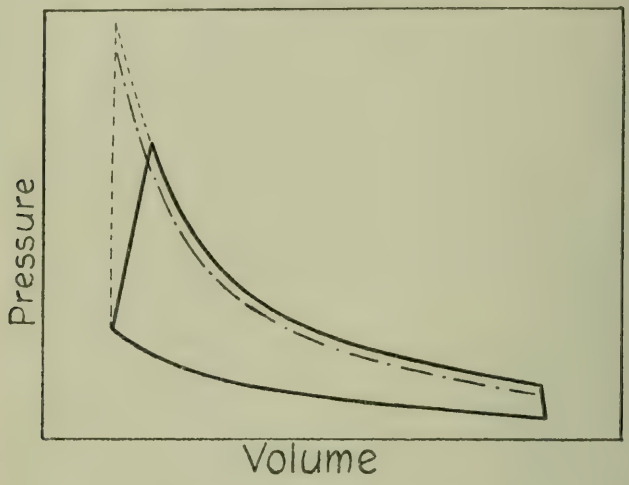
Pressure, Volume, Temperature and Intrinsic Energy Graphs for 1 *lb. of gas.*

(Occupying 18 cubic feet at 373° C. abs. and 14·0 lb. per square inch).



$0{\cdot}15 \times 10^6$ foot-lb. per lb. The total energy in the gas at the end of explosion will be, therefore, $0{\cdot}96 \times 10^6$ foot-lb. per lb. Finding this point on the intrinsic energy line and striking vertically upwards to meet the same $p\mathsf{T}$ line as before, gives a maximum explosion pressure of 510 lb. per square inch abs., assuming constant volume combustion. From Fig. 6 (page 1243), this gives an indicated m.e.p. of 138 lb. per square inch abs. Assuming the same

Fig. 12.



m.e.p., but with variable volume combustion ($\rho' = 1{\cdot}2$), the maximum pressure, it appears from Fig. 6, would be only 415 lb. per square inch abs.

The next example is taken from Mr. W. A. Tookey's Paper read before this Institution in 1914. A particular gas-engine was cited giving 87·5 lb. per square inch m.e.p., working with a final compression pressure of 135 lb. per square inch abs., and a mixture strength of 40·55 B.Th.U. per cubic foot or $0{\cdot}57 \times 10^6$ foot-lb. per lb. of cylinder contents. From the diagram of Fig. 11, it is readily determined that 18 cubic feet of gas compressed from 14·7 lb. per square inch to 135 lb. per square inch abs., occupy 3·33 cubic feet. This corresponds to a compression ratio of 5·4, which

is the same as that obtained by Mr. Tookey, although in quite a different manner. The intrinsic energy of the mixture at the end of compression is determined in the same way as before to be $0{\cdot}16 \times 10^6$ foot-lb. per lb., giving a total intrinsic energy of $0{\cdot}73 \times 10^6$ foot-lb. per lb. at the end of explosion. This further corresponds to an explosion pressure of 485 lb. per square inch abs., and from Fig. 7 it appears that constant volume combustion to this extent should give 107 per square inch indicated m.e.p. The indicated m.e.p. of the engine, which was evidently in bad tune when Mr. Tookey first tested it, was subsequently raised to 96 lb. per square inch, a decided improvement over its original value, but not as good as would appear to be obtainable in a well-designed engine.

The pressure values and diagrams thus obtained from Fig. 11, can, of course, be derived much more quickly than the time taken to describe the method would appear to indicate, and the principles of its use in conjunction with Figs. 6 to 10 as described, are readily and easily mastered.

It is to be observed that mechanical efficiency is not included as a factor in the graphs given in Figs. 6 to 11, so that in arriving at brake thermal efficiency or brake m.e.p. it is necessary to take this into account.

6. *Regeneration.*—The raising of steam by means of the waste heat of an engine and utilizing this steam in a high efficiency steam-engine or turbine, is undoubtedly the best and most practicable method of increasing over-all efficiencies. The schemes so far proposed or adopted, however, such as that typified by the recently introduced Still engine, appear to suffer very much from an undesirable increase in the mechanical details of the engine structure.

Some recent work carried out at the Manchester College of Technology (which it is hoped will be published later) by a research student, R. Koivulehto, in conjunction with the writer, on the effect of water injection on the heat distribution in a gas-engine cylinder has resulted in the determination of actual quantitative

values relating to the amount of heat diverted from the jackets to the exhaust per lb. of water injected per b.h.p.-hour.

In connexion with this, the following regenerative scheme is suggested, experimental figures being adduced in evidence of its value. The proposal is that by running a multi-cylinder engine on a maximum efficiency dual combustion cycle of compression ratio 8 or 9 : 1 an indicated thermal efficiency of over 40 per cent is possible. By water injection a large proportion of the jacket heat would be diverted to exhaust, resulting, say, in an exhaust discharge of comparatively low temperature and containing 40 per cent of the original heat contained in the fuel. Assuming 20 per cent of this waste heat to be utilized in a high efficiency turbine of the Rateau type, the total over-all efficiency would be raised to the neighbourhood of 50 per cent, and this without the introduction of any complicated steam-raising plant. The water injection also would serve to keep down the flame temperatures of the D.C. Cycle.

The following figures are typical of the results obtained in the above-mentioned water injection experiments :—

Lb. of water injected per b.h.p.-hour .	0	1·3
Exhaust gas temperature ° F. . .	722	646
Percentage exhaust heat . . .	27	44
Percentage jacket heat	34	20
B.H.P. per cent	33	30

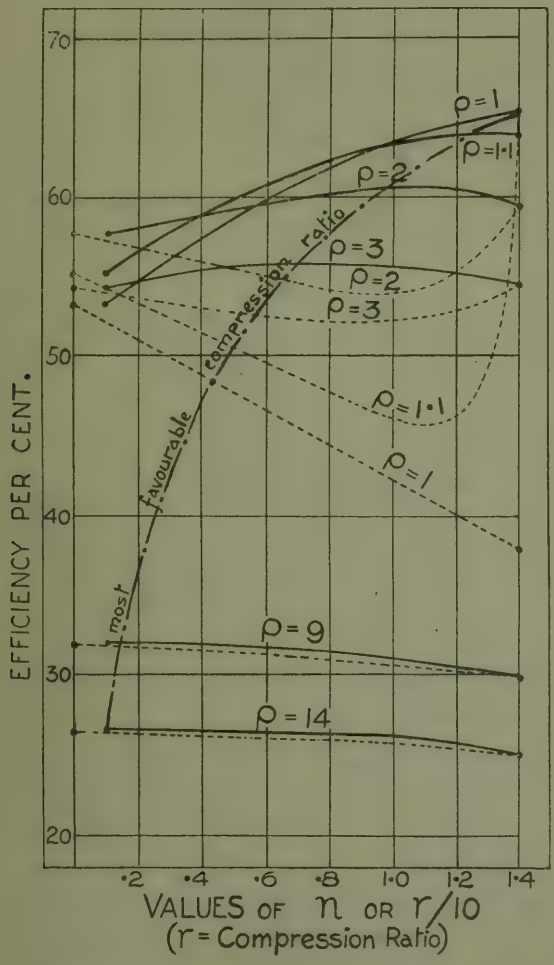
The Paper is illustrated by 12 Figs. in the letterpress.

Introductory Remarks.

Dr. William J. Walker, in introducing his Paper, said he would like to give two diagrams supplementing Fig. 5 (page 1242). The latter represented the efficiency of the D. C. cycle against compression ratio. The full line curves of Fig. 13, which is taken from a Paper read before the Manchester Literary and Philosophical Society in November last, give the same relationship for different values

of ρ in the D. C. Cycle. The chain line in the figure has been drawn through the maximum points of each of these curves. Fig. 14,

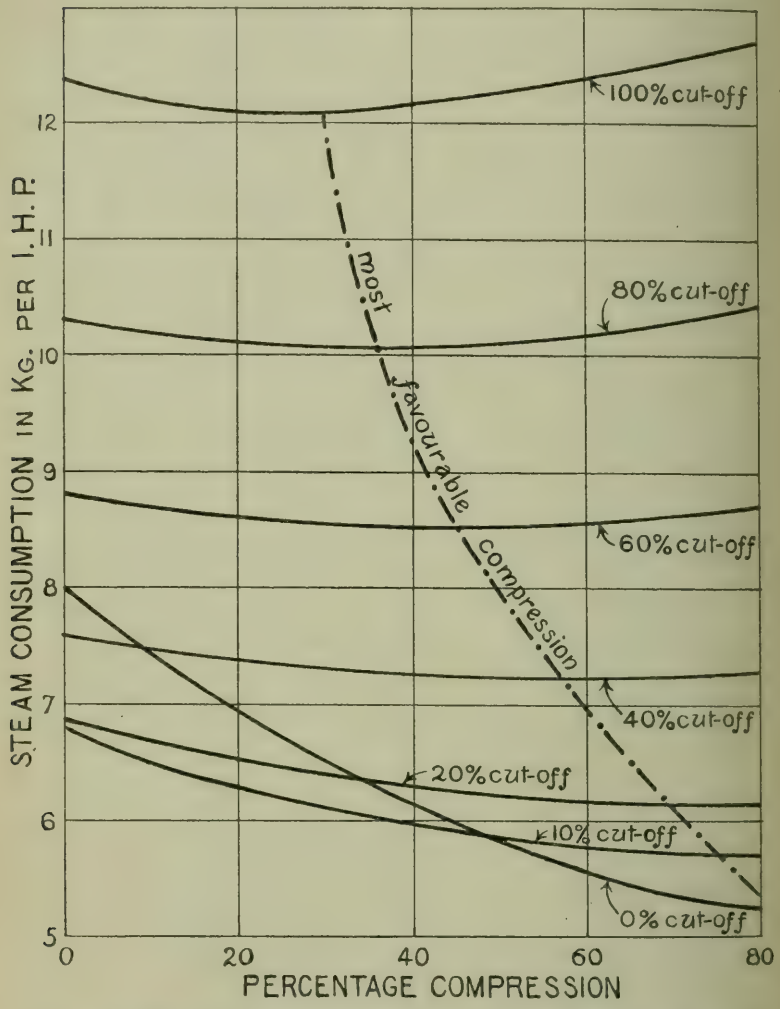
Fig. 13.



which is taken from p. 135 of Stumpf's "Uniflow Engines," gives a series of curves showing steam consumption against percentage

compression for different cut-off ratios. These curves show minimum steam consumption (that is, maximum efficiency) at

Fig. 14.



some intermediate compression in each case, and the chain line there has been drawn through the minimum points of the curves.

The uniflow engine, of which the working fluid is superheated steam, has a pressure volume diagram similar to that of Fig. 4, and the similarity between Figs. 13 and 14 is some evidence that the practical thermodynamic advantages of the uniflow engine cycle would follow the introduction of the maximum efficiency D. C. cycle for internal-combustion engines.

The importance of the factor λ in the efficiency formula at the top of page 1248 is evident, and it was this fact which led to the Author's method of arriving at the values of his variable specific heat constants A, B, and S (page 1247). Assuming a linear formula for variable specific heat, then the adiabatic curves are given by

$$pv^m e^{\lambda\tau} = \text{constant}$$

where $$m = \frac{A}{B}.$$

From this

$$\lambda = \frac{R\left(\log \frac{p_2}{p_1} + m \log \frac{v_2}{v_1}\right)}{p_1 v_1 - p_2 v_2}$$

Taking $R = A - B = 97$, and $m = 1{\cdot}44$, the value of λ was obtained as the average over a number of engine compression and expansion curves.

Discussion in London, Friday, 17th December 1920.

The President, in proposing a hearty vote of thanks to the Author for his excellent Paper, said that papers of the kind which had just been read had been frequent in years gone by. Then they were concerned almost entirely with the theoretical aspect of the question, dealing principally with the constant-volume cycle, to a slight extent with the constant-pressure cycle, and not at all with dual combustion. The Author had made a great advance by preparing the diagrams given in the Paper, especially Fig. 11

(The President.)
(page 1255), which would be of great assistance to designers of internal-combustion engines. The scales in Fig. 11 were not easily read, being divided into eights; they should be divided into tenths.

He had tried to compare the formula for efficiency given on page 1248 with the one given by Mr. Wimperis in his book and in the discussion on Sir Dugald Clerk's Paper read before the Institution of Civil Engineers. For want of time he had been unable to do so, because the notation was different, and he suggested the advisability of a uniform notation.

It was his pleasant duty to propose a formal vote of thanks to the Author, which he would ask the members to pass by acclamation.

The resolution of thanks was carried by acclamation.

Mr. E. W. PETTER said it was with some diffidence that he took part in the discussion of such a very difficult but admirable Paper, as he had not himself made a careful study of the question with which it dealt. He tried to get his brother (Mr. G. B. Petter) from Ipswich, who had carefully studied the thermodynamics of internal-combustion engines, to take his place on the present occasion, but unfortunately it was not possible. He had, however, discussed the Paper with his brother, and some of the latter's opinions were embodied in the remarks he proposed to make. Most mechanical engineers would agree with the Author that the study of thermodynamic theory in relation to the internal-combustion engine had lately stood in need of encouragement. The Paper would, therefore, be welcomed, not only for the new light which it threw upon a difficult subject, but also for the large amount of tabulated information brought together in a convenient form. Engine manufacturers were ready to explore every new avenue suggested by theory, and they did not forget that Diesel developed his engine from theoretical principles.

He desired, first of all, to deal with a non-technical point. He noticed that the Author indulged, as nearly everybody did who read a Paper on internal-combustion engines, in a little gibe at the term "semi-Diesel." Personally, he rather defended the term "semi-Diesel." It must not be forgotten that, when the type

of engine that was designated by the name of " semi-Diesel " was introduced into this country about 1910, the accepted type of engine was the low-compression engine of the Akroyd type, and some name had to be found to describe that new form of engine so far as this country was concerned. None of the terms that had been suggested was applicable. " Hot-bulb " and " self-ignition " were a very good description of the Akroyd type of engine, and, therefore, some engineers fell back on the use of the term " semi-Diesel." He thought it might be shown from the Paper that it was not such a very bad title after all. Since the Diesel engine cycle represented the constant-pressure combustion cycle, and since the semi-Diesel engine (called by the Author the dual-combustion cycle) was a combination of the constant-pressure combustion cycle and the constant-volume combustion cycle, the name " semi-Diesel " was obviously a suitable title for engines working half on one cycle and half on the other, as illustrated in Fig. 3 (page 1238).

With regard to entropy, although the Author found it futile to investigate the entropy function in connexion with the subject of his Paper, a discussion of the subject could hardly be complete without it. Many features were exhibited in an instructive form by the θ-ϕ diagram, such as the effect of variable specific heat, the heat losses and gains in compression and expansion, and the internal energy of the gas, which could be readily measured at any point in the cycle. It was true that the study of an entropy diagram of an internal-combustion engine was more complicated than that of a steam-engine, but no doubt scientists at some future date would derive the same benefit from that function, which was always difficult to define, as they had in the case of steam-engines. In the thermodynamics of the steam-engine, entropy had played a very important part and had led to the solution of many difficult problems.

With reference to Fig. 4 (page 1241), which illustrated the dual-combustion cycle with extended expansion, the Author made comparisons in favour of that cycle. It was, however, an ideal cycle and could not be realized in practice. The toe from c to d would have to be omitted, and the constant-pressure line from a to

(Mr. E. W. Petter.)

f would be reduced by reason of the partial combustion of b to a. All solid-injection engines partook of the property of dual combustion. The charge was taken in over a measured period, and the first part of the charge served to raise the compression pressure, while in some cases the injection of the remainder of the charge was deliberately prolonged in order to obtain the constant-pressure effect.

The Author made a comparison between the Diesel cycle and the dual-combustion cycle with extended expansion. The last-named feature, even if its adoption were practicable, would seriously diminish the mean effective pressure, but from a theoretical point of view the cycle was interesting, because the efficiency, instead of increasing with the compression ratio (r), as was the custom in other cycles, passed through a maximum value with increase of (r). It was important to emphasize the fact that that was only true in a limited sense, because the maximum pressure was limited. With higher maximum pressure, higher compression ratios would give increased efficiency, exactly as in other well-known cycles. If he understood the Author rightly, it amounted to the following: In the dual-combustion cycle shown, if all the points were considered fixed except the point c, there was one position of c for which the efficiency was a maximum. But the comment which occurred to a practical man was that nothing was got in this world without paying for it. Fig. 4 was a theoretical diagram, and it could not be realized in practice. The Author ignored the fact that, in the combustion b to a, oxygen was being used up which was necessary for combustion a to f, and the constant pressure line a to f was not possible of attainment. The two-stroke cycle engine was an analogous case. The power per cylinder capacity was not double that of a four-stroke cycle engine of equal dimensions, for reasons which were obviously similar in the two cases. The expression for the efficiency of a Diesel engine was :—

$$E = 1 - \frac{1}{r^{\gamma-1}} \cdot \frac{\rho^{\gamma}-1}{\gamma(\rho-1)}$$

where ρ had the signification given by the Author. Theoretically,

the efficiency increased as ρ was diminished, but practically that was not the case. If all the factors affecting combustion could be taken into account, it might be found that ρ was a function of (r). If, for instance, one could write :—

$$\frac{\rho^{\gamma}-1}{\gamma\,(\rho-1)} = r^{\gamma-1}\,\frac{A-\gamma r}{B-r^{\gamma}}$$

one might obtain a value for (r) which would make the efficiency a maximum, and that characteristic, which applied to the dual combustion cycle only in a limited sense, would apply to the Diesel cycle absolutely. Fig. 11 (page 1255) gave in a very serviceable form the quantities involved in the investigation of a thermodynamic cycle. It would be helpful if the Author would add an example of the use of the diagram in the case of a Diesel engine cycle.

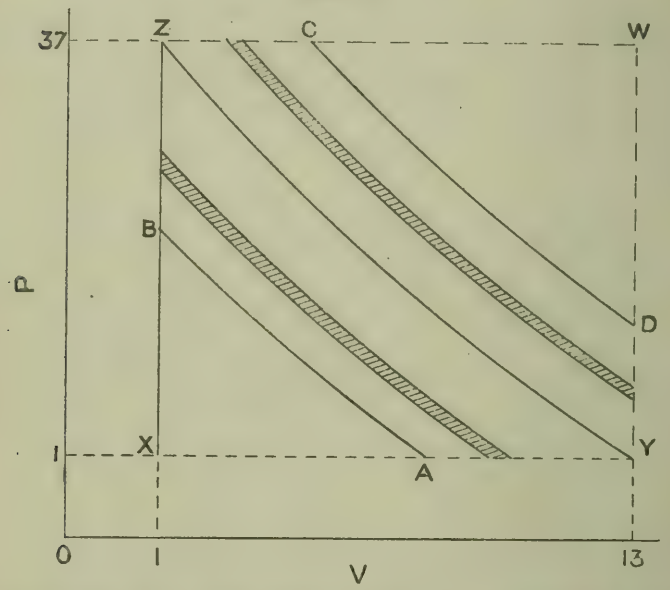
In the concluding paragraph of the Paper, the Author dealt with the question of waste heat, and recommended the use of water injection. All practical men would agree that, whatever system was ultimately adopted for utilizing waste heat, water injection into the cylinder was ruled out. The use of water for keeping down the temperatures and retarding ignition or for any other purpose could only be described as vicious. If the water contained lime, the latter was deposited on the cylinder walls with obvious results, while, in oil-engines of the kind dealt with in the Paper, which were expected to use any fuels obtainable throughout the world—many of which contained high percentages of sulphur—the use of water was destructive, as the sulphuric acid generated ate away the cylinders and pistons in a remarkably short time.

Mr. W. J. STERN said that at the Air Ministry Laboratory a certain amount of research work on aero cycles had been done ; in fact, they were keenly interested in anything which would lead to the improvement of those engines. On the previous day Mr. Ricardo gave a Paper at the Aeronautical Society dealing with that very point, and he showed that the cycle as adopted in the present internal-combustion engine was carried out most efficiently,

(Mr. W. J. Stern.)

that is, the engine really gave as much power as it could give on that particular cycle using that particular working substance, and therefore that there was very little chance of improvement. When Mr. Wimperis showed him the present Paper, they both at once realized its importance in so far as it opened out the trial of a different cycle to the ordinary cycle ; and if a bigger efficiency could be obtained with that cycle, the constant-volume cycle, which was at present being used, would be scrapped in favour

FIG. 15.



of the Author's dual-combustion cycle. But on reading through the Paper he found that some of the Author's claims were still open to doubt. He thought it would probably be of interest if he sketched out, Fig. 15, the general characteristics of the double cycle from a physical rather than from a mathematical point of view.

The rectangle Z W Y X marks the limiting points of a dual-combustion cycle working with a maximum compression ratio of 13 to 1, Z Y being an adiabatic. A B Z C D Y marks an intermediate

cycle. The various cycles are obtained by the points B and C travelling from Z toward X and W respectively. Z C D Y is the Diesel cycle proper, A B Z Y is the constant volume cycle added.

The efficiency of the whole cycle could be obtained from considerations of the efficiency of a number of very small cycles shown as shaded strips in the diagram. The efficiency of such an infinitesimal cycle was purely a function of the expansion or compression ratio, provided the specific heat of the working substance was constant.

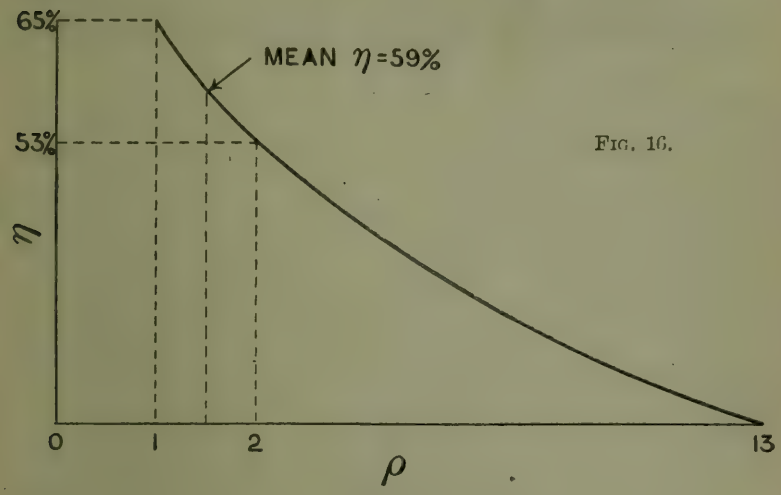


FIG. 16.

Taking first the Diesel cycle proper, it was evident that the efficiency of the elementary strips decreased as the strips travelled outward from Z Y, since the compression ratio continually diminished.

Taking ρ as the ratio of the volumes of the working substance at C and Z, a curve could be plotted between ρ and the efficiency η of the strip, using the formula

$$\eta = 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

where r is the compression ratio and equal to $\rho/_{13}$. Such a curve would have the general form of Fig. 16.

(Mr. W. J. Stern.)

At the point W, $\rho = 13$ and $\eta = 0$.
At ,, ,, Z, $\rho = 1$ and $\eta = 65$ per cent.
At ,, ,, C, $\rho = 2$ and $\eta = 53{\cdot}5$ per cent.
} With $\gamma = 1{\cdot}41$

The efficiency of the Diesel cycle for any value of ρ would correspond to the mean ordinate of the curve between the same limits. For a value of $\rho = 2$, the mean ordinate corresponds to a value of η of 59 per cent. A similar curve could be plotted for the constant-volume cycle Z X Y, connecting η and α, which is the ratio ZX/BX. Such a curve was shown in Fig. 17.

As long as the efficiency of the elementary cycles lay above the Diesel value η of 59 per cent, it paid to add heat at constant

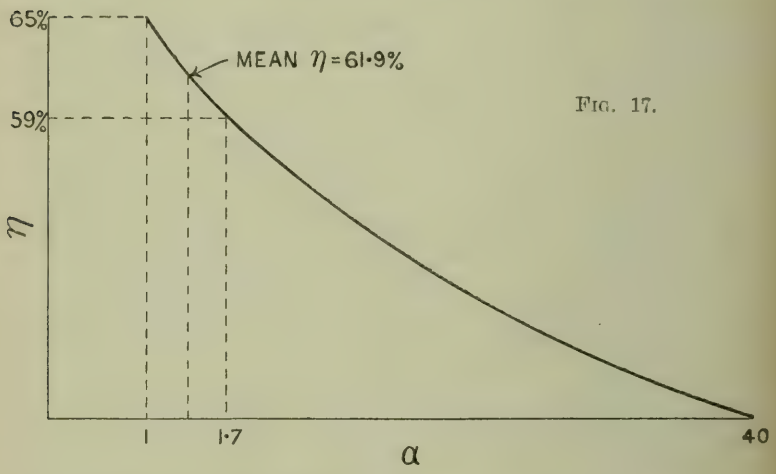


FIG. 17.

volume, the over-all η being increased thereby. For a value of $v = 13$, and $\rho = 2$, the efficiency reached a maximum for $\alpha = 1{\cdot}7$.

The constant-volume cycle η was in this case 61·9 per cent, that of the Diesel cycle proper being only 59 per cent. The efficiency of the total dual-combustion cycle was 59·7 per cent. This resultant η was not the average of the two, since the same quantity of heat was not added in the two cycles. Expressed in terms of T, the temperature at the end of compression, the Diesel cycle took in a quantity of heat equal to 0·408 T, the constant-volume portion

of the cycle taking in 0·119 T, the dual-combustion cycle thus accounting for 0·527 T.

As far as efficiency went, there was very little in it. The original Diesel cycle had an η of 59 per cent, and the dual-combustion cycle had one of 60 per cent. If the same quantity of heat had been transformed in the Diesel cycle as in the dual-combustion cycle, the efficiency (assuming constant specific heat) of the Diesel cycle would be lowered to 58 per cent, due to the increase in ρ.

The main advantage of the dual-combustion cycle was thus to maintain efficiency with increase of heat addition, or in other words to maintain efficiency with increase m.e.p. This increase in m.e.p., however, gave rise to very large increases in top temperature of the cycle. In the case considered, and assuming constant specific heat, the maximum temperature of the Diesel cycle would be of the order of 2,000° C., and that of the dual-combustion cycle well over 3,000° C. Of course, with the practical working substance these temperatures would not be reached, but there was no doubt that the dual-combustion cycle would have the higher temperature of the two. At present the main difficulties of the Diesel engine were the cooling of the piston and of the valve, and they were also the great difficulties in aero engine design. Raising the temperature would be absolutely hopeless unless, as the Author suggested, some diluent was used, such as injecting water, which might lead to other difficulties.

There was one other point in connexion with which he desired to find fault with the Paper, because it went so heavily against all the experimental work done at the Air Ministry Laboratory and elsewhere. Probably many of the members had noticed that the Author gave an example of a constant-volume cycle with a sloping combustion line, and, according to his analysis, that cycle would have a higher efficiency than the constant-volume cycle. All the experimental work that had been done in the Air Ministry Laboratory went against that. The more rapidly the heat addition could be made (even including detonation), the greater would be the efficiency. The reason for that was entirely one of cooling, which had been altogether neglected in the analysis. The Author

(Mr. W. J. Stern.)
had disagreed with the use of the entropy diagram. Yet the effect of cooling losses was brought out very clearly on such a diagram. Moreover, the study of the entropy diagram brought out clearly the fact that the Diesel cycle was not a constant-pressure cycle at all, but that a considerable proportion of the fuel (of the order of 10 per cent) burned under constant-volume conditions. The Diesel cycle itself was thus a sort of dual-combustion cycle in practice, and this must be borne in mind when criticising the above results.

Mr. A. E. L. CHORLTON, C. B. E., said the first reference made in the Paper was to the classification of types, a subject in which he was interested as a member of the Committee appointed by the Council to consider the subject. There was a very great difficulty in classifying all the types of internal-combustion engines, and he had hoped the Author would have been more specific in dividing them into the various cycles, etc., as that would have been of great help to the Committee.

The next point to which the Author referred was the advantage of extended expansion, which had not been dealt with by previous speakers. Between all that had been shown of the various cycles mathematically and on the blackboard, there was not in practice a deal of difference; he thought there were other ways by which more advantage might be obtained. One of them undoubtedly was through a longer expansion-stroke. The Author mentioned that in the Paper, but he suggested that more might have been made of it. The subject was referred to on the previous evening by Mr. Ricardo. The best example was the Humphrey pump, which had a 3 to 1 expansion stroke. Its oldest example was in the Atkinson cycle engine. This economic addition to the cycle was bound to come up again, and he would be much obliged to the Author if he would deal with it in his reply, and indicate the way in which he thought it might best be carried out. In the aero engine, one liked to vary the stroke so that there was a long suction-stroke when the machine left the ground, that is, a stroke of the largest power and a short expansion stroke, and the reverse, a short suction stroke and a long expansion stroke, when the

machine was in the air and needed to work with maximum economy.

He would like the Author to be more specific in regard to his classification of the dual-combustion engine. Could the hot-bulb engine be said to be a dual-cycle engine ? The diagram in the Paper showed the heat added at the end of the compression stroke. In working with an uncooled surface, the heat was added all the time, there was a higher suction temperature, so that it seemed to him that the only engine mentioned to which the Author's diagram really applied was the Blackstone engine, which put in the first heat near the end of the compression. All other uncooled engines were not, strictly speaking, on that cycle as drawn.

There appeared to be three groups of engines working on a composite cycle :—

(*a*) Double-injection engines, injecting oil at two different periods from two different apertures (low compression).

(*b*) Single-injection, high compression.

(*c*) Single-injection, med. compression, uncooled areas.

The flat-topped diagram was only produced by (*a*). What cycle were the Brons, Steinbecker, etc. ? Would the Author deal more specifically with this part of the subject, especially with a view to helping the Committee in their consideration of the Nomenclature of Engines ?

He was glad the last speaker had dealt with the question of the sloping admission line. After all, it was really the ignition, and it was a favourite way of working engines with an exhaust boiler, so that in that sense the Author was correct. Undoubtedly it did give better results with an exhaust boiler, but surely not with an engine alone. The quickest combustion usually gave the best results.

He was disappointed with the last part of the Paper, which dealt with regeneration. Why did not the Author treat it mathematically, as he had done the dual-combustion cycle ? They had got, leaving the engine in one way or another, more than half the heat supplied, and if they were really determined to discover some way of making economies, it seemed to him that this was a much more possible field than any of the minor divergencies of

(Mr. A. E. L. Chorlton.)
diagrams they had been shown that evening. The admission of water into the cylinder was a very questionable thing indeed, and he doubted very much whether a return would be obtained from the turbine in the manner the Author suggested, namely, working atmospherically. Was it not possible for the Author to give an analysis of an engine in which, say, a combination of a hot-air engine and an internal-combustion engine was effected, in which the waste heat was added by a regenerator as hot air at the top of the cycle? He desired, in conclusion, to congratulate the Author on his excellent Paper. He wished they had more papers on the Internal-Combustion Engine, as it was of such paramount importance to-day.

Mr. F. L. MARTINEAU said the last two or three pages of the Paper had interested him immensely. Fig. 11 (page 1255), was extremely useful, but, like the Mollier diagram, it was very easy to make an error in tracing the point across the diagram either vertically or horizontally, and a better arrangement was to convert this diagram into an alignment diagram. The Mollier diagram had been converted in that way*. It was then much more useful, because readings were direct, and all the figures could be interpolated quite easily without any possibility of error.

The other point to which he wished to refer was the question of regeneration. He thought the examples the Author had given on page 1258 were a little unfortunate, because the figures distinctly showed that, by injecting water, the combustion efficiency was decreased. Any form of regeneration used should not reduce the original efficiency as a combustion engine on the combustion cycle, because if it did, a direct loss was made of which only a percentage could be recovered. Taking the figures given a little higher up on the page, the Author suggested that 40 per cent of the original heat would be left, and of that, 20 per cent could be gained in the

* "Thermo-dynamische Rechentafel für Dampfturbinen," by R. Proell, Zeits. des Ver. deutscher Ing. Band 48, No. 38, pp. 1418, 1419. 17th September 1904. *See* also Proc. I.A.E., W. H. Gibson, Vol. xiv, pp. 659-77.

turbine. The figure he mentioned when speaking was 11 per cent; but taking the figures below, there was an actual loss of heat of 3 per cent in the figures given from 33 down to 30, while the problematic gain was only 8 per cent. As the Still cycle had been mentioned, he desired to point out that that cycle not only gave the regeneration properties due to converting heat into steam, but also put the combustion cylinder itself into such a condition that an actual gain was obtained on the combustion cycle, and not a loss due to the constant and uniform temperature of the cylinder itself. This was a very important feature of the Still cycle—that not only was a gain obtained from regeneration from the losses, but there was an actual gain in combustion efficiency. The reason was that the amount of heat which was transmitted from the combustion cylinder direct to the cylinder-jacket was a much smaller percentage than in a normal engine. As a matter of fact, it was only about 10 per cent of the total heat. Unfortunately it was not more, because the whole of the heat which passed through the jacket from the combustion-cylinder to the jacket was converted into steam at a very high percentage, there being no loss except radiation from the outside, which was a point worthy of consideration.

Mr. W. A. Tookey said he had been greatly interested in the statements made in the Paper, and more particularly in the Author's opening remarks that evening, when he showed some further diagrams (page 1259–60). He (Mr. Tookey) was not only interested in the thermodynamic cycle in relation to the internal-combustion engine, but also in connexion with the application of internal-combustion engines to actual everyday work. When he read the Paper and saw the diagrams which seemed to indicate that the Author expected to maintain mean effective pressures of anything up to 200 lb. per sq. inch, he was startled, because he considered that such an engine, as far as present-day practical knowledge went, was rather more than could be hoped for. The members would like to feel that it was possible, because, until high mean effective pressures somewhere of that order were obtained, no great extension in the way of putting internal-combustion engines into

(Mr. W. A. Tookey.)
confined spaces, such as were necessary for marine propulsion, could be looked for.

Another point which the Author had not considered, was that a great deal depended not only upon the cycle of the internal-combustion engine, but also upon the fuel which was available for use in the internal-combustion engine. It was possible to do with gas what could not be done with oil, and vice versa. He thought the Nomenclature Committee, of which Mr. Chorlton and himself were members, would, in considering the system of classification, have to take into account the kind of fuel that the internal-combustion engines were using, quite as much as the method of operation.

Finally, he desired to re-echo the words of previous speakers and say that he was disappointed to find some indication existed that the Professors in such a College as the Manchester College of Technology, which had such a high reputation, still felt that there was something in the injection of water into the cylinders of internal-combustion engines.

The PRESIDENT requested Mr. Tookey to look at page 1257 of the Paper, on which the Author said that the constant-volume combustion should give 107 lb. per sq. inch indicated m.e.p., whereas the figure given in Mr. Tookey's Paper was 96 lb. per sq. inch.

Mr. TOOKEY said he had naturally been interested in the figures the Author had mentioned, and to see that the chart the Author had drawn out confirmed that the method he (Mr. Tookey) adopted, in connexion with the Paper read before the Institution in 1914, was right in computing the compression ratio. The Author, however, made the statement: "The indicated m.e.p. of the engine, which was evidently in bad tune when Mr. Tookey first tested it, was subsequently raised to 96 lb. per sq. inch, a decided improvement over its original value, but not as good as would appear to be obtainable in a well-designed engine." That, of course, was not realized at the time, because he had not the pleasure of having Dr. Walker's Paper before him in 1914. Personally, he would have

been rather surprised to find any mean effective pressure of 107 lb. or over 100 lb., and he would at once have taken steps to reduce it, because in his opinion, as far as the practice of internal-combustion engineering went, any mean pressure in an engine well over about 95 lb. and certainly over 100 lb. was an unsafe mean effective pressure at which to work at the present time. He did not say the Author was wrong, as it might be that the engine could be tuned up to the figure stated, but certainly if that had been done, he would have tried to get the same efficiency with a rather weaker mixture strength.

Mr. LOUGHNAN PENDRED (Member of Council) said the Author had drawn an interesting comparison by means of the diagram, Fig. 13 (page 1259), between the uniflow engine and the gas-engine, and had shown that there was a curious resemblance between them, in that, as the compression went up, the efficiency increased. He could not think that there was any real physical basis for that curious fact, but it was such a remarkable coincidence that he hoped the subject would be dealt with further by those who were interested in making such inquiries. It was at least a curious thing that, as had been pointed out, the curves for two engines so totally different in all respects, and in which the effect of compression was of an entirely different kind, lay almost exactly upon each other.

In the Paper and in the discussion frequent reference had been made to constant-pressure cycles and constant-volume cycles; but, as had been pointed out by several of the speakers, neither of those definitions, if they might be so called, was correct. He thought it might be desirable for the Nomenclature of Oil-Engines Committee to consider whether terms which did not describe a cycle accurately should be retained.

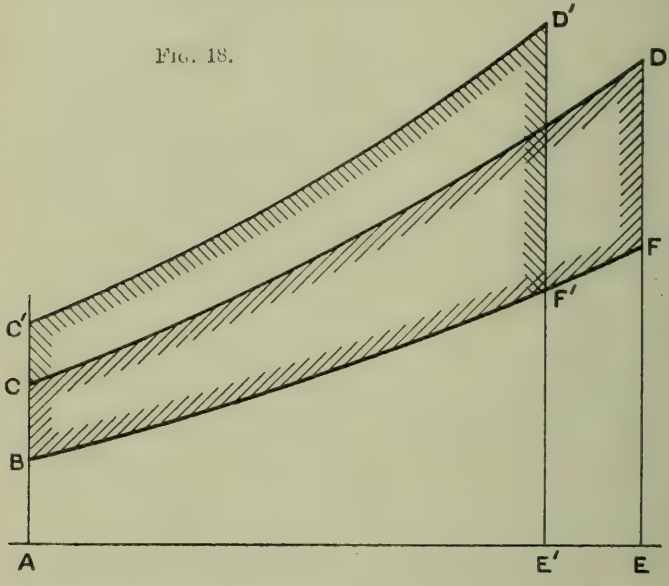
The PRESIDENT explained by means of the θ–ϕ diagram, Fig. 18 (page 1276), why a greater efficiency was obtained with a high compression than with a low.

If the state point of the combustible mixture in the cylinder, at the beginning of compression, was represented by B, the

(The President.)

compression was represented by the vertical line B C. On explosion, the state-point moved along the constant-volume line C D, and the area A C D E represented the total amount of heat produced by the combustion. Adiabatic expansion then occurred, and the state-point moved along D E until at F the same volume was reached as at the beginning of compression; and the cycle was completed by the constant volume line F B. The thermal efficiency of the cycle was the ratio of the shaded area to the original area.

Fig. 18.



If there was a greater compression ratio, the point C′ was reached and combustion took place along the constant volume line C′ D′. The point D′ was such that the area A C′ D′ E′ was the same as before. The shaded area B C′ D′ F′ was obviously greater than in the first case, hence the thermal efficiency was greater. The reason greater efficiency was obtained by increased compression in the case of the uniflow engine was totally different; it was merely due to the fact that the cylinder walls were warmer, and hence there was less initial condensation.

Dr. W. J. WALKER, in reply, thanked the members sincerely for the kind reception accorded to his Paper, but at the same time desired to express his regret that apparently there were no adherents to the water-injection proposition given at the end of the Paper. He proposed to deal very briefly with a few of the points which had been raised.

The President had referred to the scale divisions in the diagram of Fig. 11 (page 1255). That diagram was a very much reduced facsimile of the original one. He had never had another drawn up himself, but his students had drawn such diagrams with more conveniently divided scales. In the present instance, however, he had retained the original diagram for publication, and the division of that was determined more by the type of squared paper available at the time than by anything else. Another point raised was the apparent dissimilarity between the formula for the efficiency of the C.V. cycle given by Mr. Wimperis, and that deduced from the general formula given on page 1248. In his written reply he would show that the one could be directly transformed into the other.

Mr. Petter had referred to the Author's criticism of the term "semi-Diesel." The Petter engine, the Bolinder engine, and several others of the same type did not give constant-pressure combustion; he had looked in vain for any indication of constant-pressure combustion on the indicator cards of such engines. His selection of the Blackstone engine as the most typical D.C. engine was due to the fact that the constant-pressure line was very distinct in diagrams from this engine, and so was the differentiation between the constant-volume combustion process and the constant-pressure combustion process. With regard to the other engines mentioned in the Paper, these were selected as typical of foreign practice, and not because of any inherent superiority over those of English make, the Sabathé being typical of French, the De la Vergne of American, and the Trinkler-Körting of German practice. The Trinkler-Körting type of engine was possibly not one which had had much development, but the diagrams published in the Paper to which reference was made in the footnote on page 1240 showed distinctly the two stages of combustion.

(Dr. W. J. Walker.)

His reason, for stating in the first paragraph that he considered little advantage was derived from applications of the entropy function, was that in all his work he had usually had complete satisfaction in pressure, volume, temperature and energy quantities. He did not say that the entropy function was not of any use, but for general design it was invariably not required. If one encountered a difficulty of any kind which could not be cleared up by reference to pressure, volume, temperature or energy lines, the construction of an entropy diagram usually helped matters, but his own attitude was to leave entropy diagrams alone until forced to use them.

The practicability of the D.C. cycle was also referred to by Mr. Petter. That point had been raised by several of the speakers and indicated, as far as he (the Author) could judge, a certain amount of difference of opinion on the subject. Referring to Fig. 4, which represented the D.C. cycle with compression starting at point *c*, he did not see any radical objection to the compression starting anywhere on a stroke. In the maximum efficiency D.C. cycle greater expansion was obviously obtained than in the ordinary cycle giving compression-volume expansion only. The most important point (already emphasized in the Paper) to be noted about the D.C. cycle was that, when compared with the C.V. and C.P. cycles, it was the only one of the three which gave increased efficiency at a lower compression ratio than that possible within given pressure and volume limits. His favourable opinion of the D.C. cycle was also based partly on the fact that the compression ratio could be diminished, thus reducing mechanical losses, which was in itself an advantage, apart from any purely thermal gain. Temperatures at point *f*, Fig. 4, were obviously higher in the D.C. cycle than in the Diesel cycle, but it should be remembered that, in obtaining the curve of Fig. 5, the only limitation made in comparing the several cycles was that of the same maximum pressure in each case. If the further limitation was imposed that the amount of oil burned per lb. of air was constant, then the temperatures at the end of combustion would be the same in each case and the maximum efficiency point of the D.C. cycle would be higher than

shown in Fig. 5, and would take place at an even lower compression ratio than before.

Mr. Stern (page 1269) had said that the sloping combustion line diminished the efficiency, but his (the Author's) experience was quite the other way. Even in slow speed gas-engine work, he could always get a higher efficiency with a variable volume combustion line. Of course, there was a limit to the slope of the line, which, so far as he could make out from his theoretical deductions, appeared to be given by a value of 1·2 for ρ'. (*See* page 1248 and Fig. 12). Anything beyond that diminished the efficiency; anything less also gave smaller efficiencies.

Mr. Chorlton had referred (page 1270) to the incompleteness of his classification of engine types. As a matter of fact, that classification was submitted as one way of clearing the ground. It appeared broad enough to include all types, but was of course capable of much sub-division. It was his (the Author's) method of classification when lecturing on the subject. The use of the term "semi-Diesel" (and such like), rendered one responsible for its definition, and for his part he had never been able to do this satisfactorily. The classification was based wholly on the scientific definition of the three most important factors in engine operation :— (1) ignition; (2) method of operation; and (3) thermodynamic cycle.

The diagrams for the uniflow engine were obtained from theoretical calculations, and not from experimental data. The point raised by the President, therefore, that the higher efficiency at the lower compression might be due to diminished condensation could not hold, since the curves were not practical test-curves, but curves deduced from the cycle followed by the engine.

Discussion in Manchester, Thursday, 23rd December, 1920.

The CHAIRMAN (Professor A. H. Gibson, D.Sc.) said that, in view of the present price of fuel, there was little need to emphasize the importance of an exploration of every avenue through which the

(Professor A. H. Gibson.)

efficiency of the internal-combustion engine might be increased. In one direction, at all events, they seemed to have very nearly attained the limit of the possible. Taking the air-cycle efficiency, as modified for the variable specific heat of the working fluid, as representing the maximum possible in any engine working on the ordinary constant-pressure or constant-volume cycle with equal expansion and compression ratios, modern high-speed petrol-engines with compression ratios between 5·0 and 6·0 were capable of giving efficiencies as high as 90 per cent of those theoretically corresponding to their compression ratio. So that, even if all heat losses due to the cooling effect of walls, piston, and other sources, could be eliminated, the resultant gain would only be an increase of some 10 per cent on their present performance, or of some 3 per cent on their actual efficiency.

It was true that if they could increase the compression ratio of the ordinary constant-volume engine still further, its efficiency might be increased, but a limit was soon reached, owing to the fact that the compression temperature became sufficient to produce spontaneous combustion and pre-ignition before the end of the compression stroke. One possible partial solution of this difficulty was to be found in the selection of fuels or fuel mixtures having high self-ignition temperatures. Investigations now in progress indicated that something was to be expected in this direction, and that the normal compression of an aero engine might be raised from about 5·0 to 7·0 in this way, with a possible gain in efficiency of about 15 per cent. This, however, while extremely useful, was only a partial solution of the problem. In his Paper, Dr. Walker indicated other possible lines.

Dr. T. B. MORLEY said he had always taken a great interest in graphical methods of computation, and Fig. 11 (page 1255) attracted his attention. He was rather interested to discover whether the exceedingly interesting and valuable Figs. 6 to 10 had been evaluated by the use of the chart in Fig. 11 or by arithmetical calculation.

Dr. WALKER said they were quite separate.

Dr. MORLEY said that anyone who had studied that kind of thing would appreciate the enormous amount of labour which must have been put into the preparation of those Figs. 6 to 10, and his own efforts in the way of charts were directed to the elimination of as much as possible of that labour. In 1914 he published a chart for gas-engine mixtures which was intended to facilitate calculations involving variable specific heats.*

[At this point Dr. Morley sketched the chart and explained its construction and use.]

Since seeing Dr. Walker's Paper he had drawn out a chart† on similar lines to his previous one, but extended to higher temperatures and based on the specific heats given by Dr. Walker. Also he had found it an improvement to plot the intrinsic energy to a logarithmic instead of a uniform scale as in his 1914 chart. This facilitated the accurate reading of the energy values, since with the extended temperature-range a curve plotted to a uniform scale would have been very steep at the lower temperatures.

It was easy to calculate engine cycles when one had made the chart, and the labour in making it would, he thought, be less than the labour which the Author had expended in getting out the curves in the Paper. He had used this chart (which he had made rather roughly in the last day or two) to check over one of the examples given by Dr. Walker, but before indicating the comparison, he would like to make some remarks with regard to the data upon which these diagrams were made.

He was interested in the specific heat values referred to on page 1247. The diagram which he published in 1914 was based upon specific heat data, which, at the date of writing it, early in 1914, were, he believed, the latest and most reliable then in existence, and they included a T^2 term—that was to say, the specific heat value was $a + s\,T + u\,T^2$. He appreciated Dr. Walker's remarks about the T^2 term being for practical purposes negligible, and it certainly simplified the calculation to leave it out. However, he would like

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* *Engineering*, 18th December 1914.

† *See* Fig. 21 (pages 1298–9) accompanying written contribution.

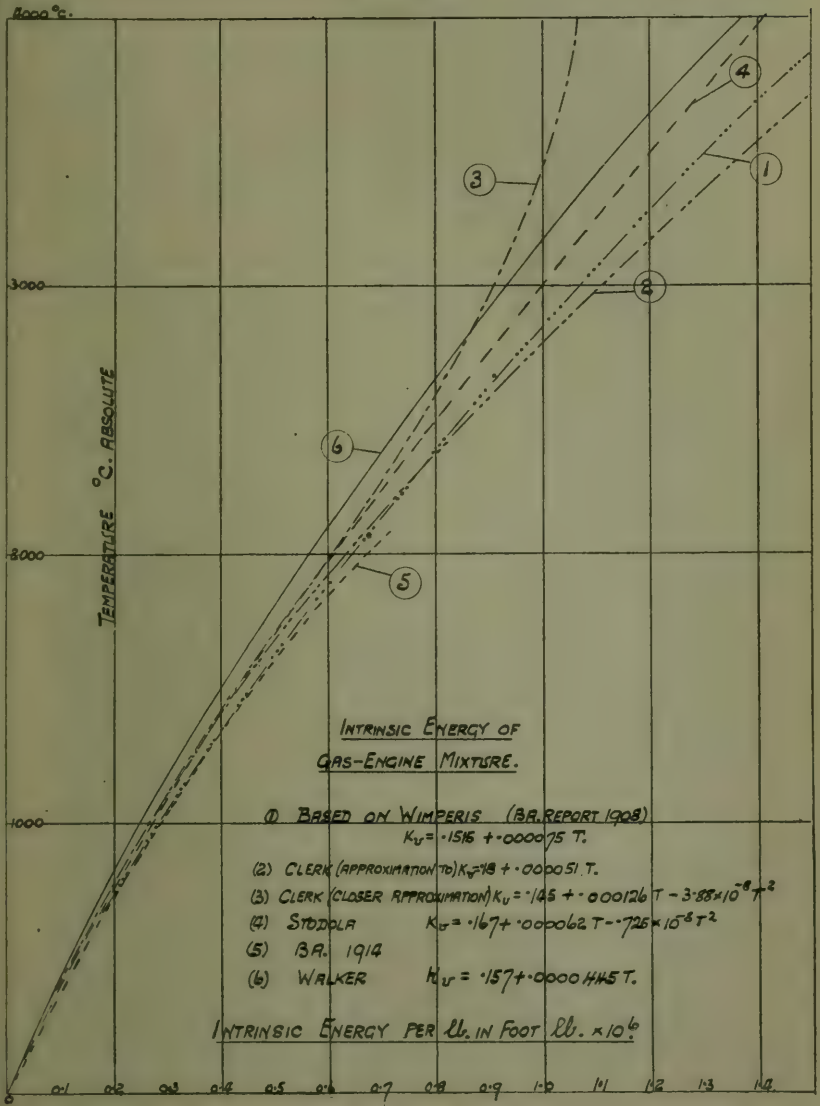
(Dr. T. B. Morley.)

to know whether the Author had worked out the constants upon page 1247 from the examination of actual indicator diagrams or whether they were based on the determinations of physicists. At the bottom of page 1245 the discarding of this T^2 squared term was referred to—namely, "Values due to Pier and Bjerrum are, however, now available," and then he gave references in a footnote to the Papers containing their results. What struck him (Dr. Morley) was that those references were all dated earlier than 1914—the last one was dated 1912—with the exception of the one in the *Automobile Engineer*, which he inferred was based upon the others, and was not original work. The values published in 1912 by Professor Stodola were of the type including a term in T^2, and he believed that at that date they were the most reliable. Subsequent writers on the subject had also accepted Professor Stodola's figures. It was very interesting in connexion with the abolition of the T^2 term, to find that a recent writer* in Germany had been discussing a diagram for the study of oil-engines, and while he had referred to Stodola as the authority from whom to take the values of specific heats, he did not mention this T^2 term, so that one could only conclude that subsequent to 1912 Stodola himself had obtained evidence which justified the dropping of this term. The figures given for the specific heats by the German writer, who had written in the last year, were the same—with the omission of the T^2 term—as those which he himself used in 1914.

He had plotted out a diagram showing the comparison of the intrinsic energy and temperature curves based upon the specific heat constants due to various authorities, Fig. 19. He would like to ask the Author upon what grounds he could justify the extension of Fig. 11 to 4,000° C. As far as he knew, the only reliable experimental evidence was up to 2,000° C. The British Association Gaseous Explosions Committee had published curves of energy and temperature from which curves 1 and 5 of Fig. 19 were obtained. Curve 2 represented a formula which had been quoted as agreeing with Clerk's experiments. He had himself found a formula which

* Zwerger. Zeit. d. Vereines Deutsch. Ing., 27th December 1919.

FIG. 19.


4000 °C.
3000
2000
1000
0
TEMPERATURE °C. ABSOLUTE
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
1·3
1·4
INTRINSIC ENERGY PER lb. IN FOOT lb. × 10⁶
1
2
3
4
5
6
INTRINSIC ENERGY OF GAS-ENGINE MIXTURE.
(1) BASED ON WIMPERIS (B.R. REPORT 1908)
$K_v = \cdot1515 + \cdot000075\ T.$
(2) CLERK (APPROXIMATION TO) $K_v = \cdot148 + \cdot000051\ T.$
(3) CLERK (CLOSER APPROXIMATION) $K_v = \cdot145 + \cdot000126\ T - 3\cdot88\times10^{-8}T^2$
(4) STODOLA $K_v = \cdot167 + \cdot000062\ T - \cdot726\times10^{-8}T^2$
(5) B.R. 1914
(6) WALKER $K_v = \cdot157 + \cdot0000445\ T.$

(Dr. T. B. Morley.)

fitted Clerk's results—up to 2,000° C.—more closely, and this gave Curve 3. Incidentally, it should be noted that extending a formula beyond the range of the experiments on which it was based was a very unreliable proceeding, as was evidenced by the upper part of Curve 3; the backward bend was due to the increasing effect of the T^2 term, which had a negative coefficient. Curves 4 and 6 corresponded respectively to Stodola's and Walker's values.

On proceeding to work out on his chart one of the examples which Dr. Walker had given at the end of the Paper, he at once struck a difficulty which the Author had corrected that evening, namely, the use of 13 lb. per sq. inch instead of 14 lb. per sq. inch for the pressure (page 1254, line 6, and page 1255, line 3).

Taking the second of the two examples, he had plotted out the cycle on his chart. One could then read off pressures, temperatures, and volumes from the curves, and then, passing on to the internal energy line, one could read off the internal energy on the top scale. On account of the discrepancy between the initial pressures, 13 lb. and 14 lb. per sq. inch, he had taken two diagrams corresponding to each of these pressures. The mean effective pressures were 120 and 123·5 in the two cases, and the efficiencies 44·2 per cent and 42·6 per cent. He then turned to the results given on page 1257 corresponding to the same example, and found that Dr. Walker gave 107 lb. per sq. inch as the indicated m.e.p. He thought that must be a slip, because it referred to an explosion pressure of 485 lb. per sq. inch.

Dr. Walker said the reference on page 1257 should be to Fig. 7. (This correction has now been made in the Paper.)

Dr. Morley said that a point was still left to be explained, as to why the m.e.p. obtained from a diagram based upon Dr. Walker's constants was 120 by his method as against 107 in the Paper. Perhaps the Author would say whether the data used in calculating the curves in Figs. 6 to 10 corresponded to the data used in Fig. 11.

Dr. Walker replied that the whole of the values were calculated

directly, and then the curves drawn, and Figs. 6 to 10 were based upon specific heats.

Dr. MORLEY said he looked forward with very great interest to the further Paper which the Author had promised, with regard to the results obtained with water injection. With regard to the results to be obtained by generating steam from the waste heat of the gases, he thought that was a very interesting question and one that had been studied to a considerable extent, particularly in Germany and by the makers of large gas-engines of the horizontal slow-speed type. Some figures which were recently published might be of interest. They were taken from an actual acceptance test of a German engine, the gas-engine efficiency being reckoned on b.h.p., which was not measured directly, but taken from the i.h.p. with an estimated mechanical efficiency. The gas-engine efficiency was 28·6 per cent, and the heat utilized in the boilers (which were supplied with the waste heat from the engine) was 22·6 per cent. Assuming that 25 per cent of that could be utilized by a steam-turbine as effective work, that gave 5·7 per cent of the energy of the original gases, and a total thermodynamic efficiency of 34·3 per cent, quite a long way short of the 50 per cent which Dr. Walker expected to get.

With regard to the application, or the bearing upon practice, of the Author's results, he did not propose to say anything at the moment, but it should be borne in mind that it was not always efficiency that one ought to look for, and the direction in which one ought to seek for progress was in higher mean effective pressure rather than in increased efficiency. It would be a good thing if they could use higher mean effective pressures, without any deleterious effect upon the life of the engine, even at the sacrifice of efficiency. That was very pronounced if one analysed the costs of production of power, because it would be found that in engines of the large type the capital charges formed an exceedingly large proportion of the total cost of power generation, and that a saving on those capital charges would go a very long way to offset a considerable increase in the consumption of fuel or even in the cost of maintenance. (*See* also page 1297.)

Mr. J. Hutton said he had looked upon the Paper from the point of view of a commercial engineer. Dr. Morley had gone over part of the ground that he (Mr. Hutton) had intended to cover with reference to efficiency and its bearing upon capital cost, and the point had been ably presented that efficiency was not a thing to be aspired to, if it was not consistent with the cost per unit of power developed. He would therefore not discuss this matter, but come at once to the question as to how the Author proposed to obtain in practice the benefit of his proposed cycle.

He did not see in the Paper any reference to the present-day progress of the dual-combustion cycle. In other words, if one examined engines that were running to-day on the dual cycle, they would find that in a remarkable degree they bore out the assertions or anticipations of the Paper, which were so far correct that an analysis of an engine test would show that the indicator diagrams taken on the dual cycle had a value for Dr. Walker's figure of $\rho = 1 \cdot 22$ very close to the maximum efficiency point on Fig. 10 (page 1253). This type of engine was being run at the present day with the excellent efficiency of 39·5 per cent on the I.H.P. This was on engines which had been installed after ordinary Works' test and passed by a consulting engineer for client. The compression ratios were in the range of 8 to 10 as shown in Fig. 5 for maximum efficiency. The maximum pressure in most cases was slightly in excess of the 500 lb. taken by the Author. If one inserted a curve of this dual-cycle engine instead of the constant-volume cycle given in the Figures in the Paper, one would find the prospect for increased efficiency at present in the Author's cycle was only attributable to increased expansion, if compared on the same cycle of temperatures.

Most engineers were aware that increased expansion was not a commercial proposition, as the efficiency did not compensate for the cost of increased scantlings of the engine. Taking the other point which Dr. Morley had also brought forward, namely, that increased power was the object desired, the Author had pointed out that he was to obtain this by a cycle of temperatures much in excess of the Diesel engine. He (Mr. Hutton) was quite aware

that cycles of temperature could be increased at the present time, particularly in engines of the solid-injection type where the mixing was more uniform and not local, as was often the case in the Diesel engine. Seeing that this power was going to be obtained by (should he say) the higher temperature cycle, they must agree that with regard to small engines in which efficient cooling was quite possible, Dr. Walker's cycle would probably be successful. But over a certain limit of cycle of temperatures in large engines, where the stress was increased so greatly due to these temperatures, he thought the Author would have a problem which would cause objection to the cycle.

Going a little further with this question of power, they found how the Author proposed to obtain more power—that is, he was going to consume more oil per cubic foot of air. The question the commercial engineer asked himself was, " How is this to be done ? " They were quite aware that small engines—aero-engines, motor-car engines, tank-engines, or any paraffin engine that drew its fuel in at or near atmospheric pressure—could burn oil with a theoretical quantity of oxygen or air, but when they came to engines in which the compression was above the pre-ignition limit, they met with a different proposition altogether. They were faced with what might be termed the sprayer efficiency. As the volume decreased, due to compression, they had to have an excess of air, and it was at this point only he thought—not the cycle of temperatures—that at present limited the output of power in this dual type of engine. If the Author could put a sprayer proposition forward that would so increase the mean pressure of the engine without discoloration of the exhaust, that is, to consume oil efficiently at practically theoretical air mixture, he would have made a big step forward for the internal-combustion engine, but it was not so clear that he would have made a big step forward for his scheme. Personally he (Mr. Hutton) was of the opinion that if such an advance was made, and was applied to existing engines of the dual-cycle type, they would be just as good commercially as the " Walker " cycle engine.

With regard to the Author's remarks about dual injection,

(Mr. J. Hutton.)

he was of the opinion that this was the first thought of internal-combustion engineers, and the next thought, for simplicity, was to get the fuel through one sprayer. It was obvious that they would use two cams for operating the oil-pumps, that is, what they termed the preliminary injection and final-injection cam. This method had been tried, but it was found in practice that one continuous cam operating fuel-pump gave as good and even better results than two cams. When using fuels that were very heavy and where the compression pressure was too low and not capable of igniting the fuel, then the method of injection mentioned by the Author was used; but here again it was used in one sprayer if possible, as for instance, in the Crossley and Gardner types.

Having been experimenting for a long time on engines, he was pleased to see Fig. 5 (page 1242) as it showed the efficiency possibilities of the dual cycle. His opinion was that the conditions arrived at in practice, that is, 270 to 350 lb. compression with a compression ratio as stated by the Author, namely, 8 to 10, were due to what he had termed the sprayer efficiency. Further, he thought it worthy of mention, that internal-combustion engineers of to-day were quite aware that, with incomplete combustion, they could get power, or mean pressures 20 per cent and more above the rating at which the engine was sold, but the sprayer apparatus was delicate, and in unskilled hands might get out of order; therefore they left the excess power to be a margin as an insurance for reliable operation of the engine.

Mr. Telford Petrie said that the value of the Paper lay in the fact that the Author appeared to have carried the systematic application of thermodynamics to internal-combustion engines further than had been done before in England. He ventured to predict that charts of the nature of Fig. 11 would be found as useful in internal-combustion engineering as the Mollier chart had proved to be for steam.

The accuracy or otherwise of such charts ultimately rested upon the values assigned to the constants A, B, and S of the apparent specific heat formulæ on page 1247. The accompanying graph,

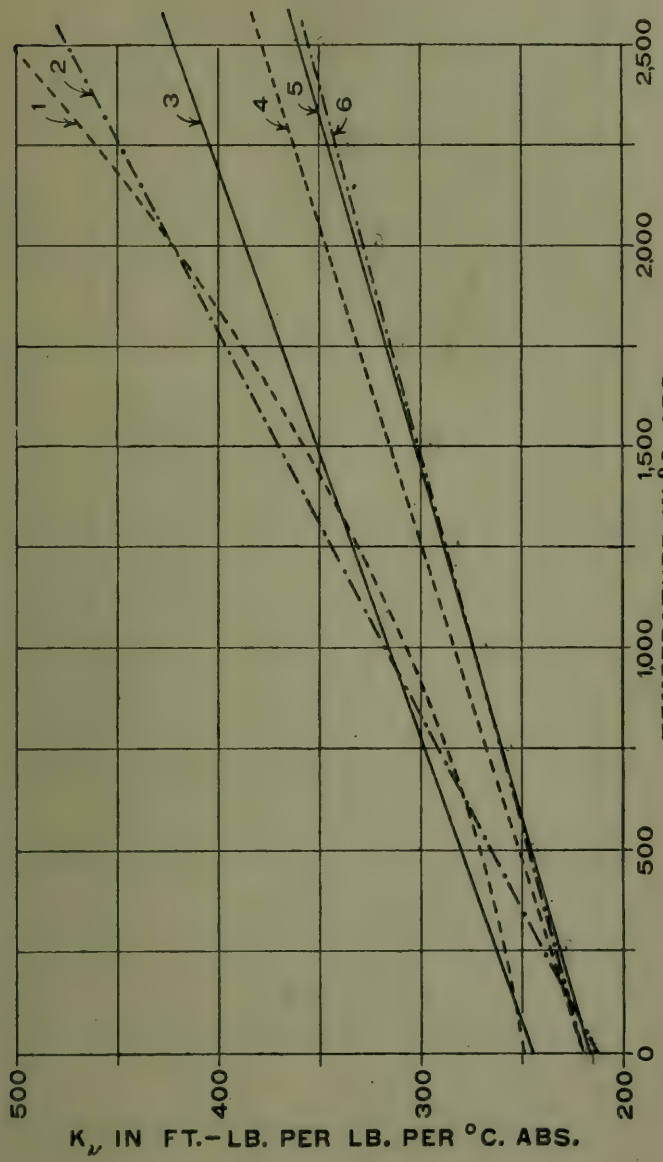

1
2
3
4
5
6
2,500
2,000
1,500
1,000
500
0
TEMPERATURE IN °C. ABS.
500
400
300
200
K_v IN FT.-LB. PER LB. PER °C. ABS.

FIG. 20.

(Mr. Telford Petrie.)

Fig. 20, might help to show at a glance how the Author's values compared with those of other recognized authorities. These curves represented the apparent specific heat at constant volume reduced for comparative purposes to the Author's units of ft.-lb. per lb. per °C. abs. They were obtained as follows :—

Curve 1.—Sir Alfred Ewing * $249{\cdot}6 + 0{\cdot}0265\,T + 29{\cdot}9 \times 10^{-6}T^2$.
„ 2.—H. E. Wimperis † $212{\cdot}8 + 0{\cdot}105\,T$.

These two values were derived from the work of the Gaseous Explosions Committee of the British Association.

Curve 3.—Sir Dugald Clerk ‡ $245 + 0{\cdot}0714\,T$.
„ 4.—Dr. Walker § $220 + 0{\cdot}0623\,T$.
„ 5.—Dr. Langen ¶ (for oil mixture) $217 + 0{\cdot}0575\,T$.
„ 6.—Löffler and Riedler ** (for air) $221 + 0{\cdot}052\,T$.

As the point where Curves 1 and 2 crossed was 2,000° C. (abs.), it would appear for all practical purposes that the T^2 term was not necessary for internal-combustion engine work. The difference in the slope of these results and the Author's (Curve 4) was very considerable; it amounted to something like 22½ per cent at 2000° C. (abs.). On the other hand there was less than 5 per cent difference at the same point between the Author's and the Continental curves 5 and 6. The importance of this slope lay in the fact that it was determined by the value assigned to S, which in turn determined the ratio $\frac{S}{B} = \lambda$, and if λ was much greater than 0·000283 (the Author's value given on p. 1247), it was possible to get ideal theoretical efficiencies from formula 5 less than those already obtained in actual engines. It was interesting to note that

* "Thermodynamics for Engineers" (1920), page 253.
† "The Internal Combustion Engine" (1919), page 79.
‡ Deduced by H. E. Wimperis, Proc. Inst. Civil Eng., vol. clxix. (1907) page 171.
§ Present Paper (1920), page 1247.
¶ Quoted in "Zeits. d. Ver. Deutsch Ing.," vol. lx. (1916), page 279.
** Quoted in "*Oelmaschinen*" (1916), page 488.

the slope of Clerk's Curve 3 was very little greater than the Author's, in view of the fact that Clerk's values were also obtained from experiments carried out in an actual engine. It appeared to him that probably the values given by the Author would have to be substituted for the higher sloping curves used in the past.

Mr. G. E. WINDELER congratulated the Author upon his very able exposition of what was oftentimes an exceedingly difficult matter to put in the form of curves. The question of the dual-combustion cycle was very interesting, but the burning of more fuel, as indicated by the Author, would necessarily increase the temperature, and he thought that those who had to deal with the practical construction and testing of these prime movers would readily agree with him that at the present time they had not suitable material with which to construct motors to work at very greatly increased temperatures. In large engines this applied particularly, as was seen by the efforts made by various designers to water-cool such parts as were exposed to the temperatures in combustion chambers.

The water-injection test touched upon just briefly by the Author was very interesting. Within recent years those who built oil-engines with surface ignition had used water injection and had given it up, because certain structural defects occurred internally in the engine, such as the oxidation of parts. One was quite prepared to admit that corrosion took place more readily with some fuels than with others, for instance, those containing a high percentage of sulphur.

One of the speakers had mentioned that, in a solid-injection engine, the mixing of the fuel with the air was more uniform than in a Diesel engine. He did not agree with that statement, because he had not seen any engine of the solid-injection type which gave such complete combustion as the Diesel engine. The Author had referred to the method of initiating combustion in the Diesel engine employing heavy tar-oils as a fuel. Did he refer to the specific gravity or the viscosity of the oil when he used the word "heavy"?

Dr. WALKER said he meant the viscosity of the oil.

Mr. WINDELER said that there was not a high percentage of viscous material in tar oils, which were generally mobile in character.

The CHAIRMAN said he would like to wind up the discussion by stating some of his own difficulties. In Figs. 6 to 10 it was interesting to note that the maximum efficiency was always attained with a value of the cut-off ratio equal to or slightly less than 1·2. This corresponded to a very slight amount of burning at constant volume. In the case of a compression ratio of 5·0, it meant that combustion was to be complete at $\frac{1}{20}$th of the stroke, and with a compression ratio of 13·0 at about $\frac{1}{65}$th of the stroke, values which would be attained in practice in a constant volume cycle with a very slight degree of after-burning, after passing the dead centre. In view of this, it was a question whether the normal constant-volume engine did not owe some of its apparently high efficiency to the fact that it was really a dual-combustion engine operating under very nearly maximum efficiency conditions.

Was there any experimental evidence to show that by diminishing the compression ratio of a Diesel engine and introducing combustion of fuel at constant volume, the efficiency might be increased as stated on page 1244? The Diesel engine in the Whitworth Engineering Laboratories of the Victoria University was, for some little time, operating on such a cycle, owing (he might say) to leakage of the fuel-valve. The compression pressure, it was true, had not been reduced, and the pressures obtained were, of course, extremely high, but the thermal efficiency under those conditions was very distinctly less than under normal operating conditions.

As regards the efficiency and mean effective pressure lines shown in Fig. 9 (page 1252), these did not agree very well with his own experiments on petrol-engines, where the product of efficiency and mean effective pressure was very nearly constant over a fairly wide range of mixture strengths, ranging from that

giving maximum efficiency to that giving maximum power. Taking a typical example, an engine giving a thermal efficiency of 0·29 with a mean effective pressure of 160 lb. per square inch would give 0·38 efficiency with a mean effective pressure of 120 lb. per square inch, instead of 0·32 as indicated by the lowest constant volume curve of Fig. 9.

The statement on page 1247 that the effectiveness of the cooling system did not affect the brake thermal efficiency, except in so far as it affected the volumetric efficiency, seemed to require some qualification. Actual tests, he thought, showed that an increase in wall temperature, by increasing the tendency to detonation—he was speaking now of an air-cooled engine in particular—did reduce the maximum practicable value of the compression ratio and hence the maximum thermal efficiency. In an engine with inadequate cooling, working near its maximum output, the thermal efficiency was increased, if the volumetric efficiency was reduced by throttling, owing to the fact that detonation was thereby prevented.

Regarding the pv curves of Fig. 11 (page 1255), those appeared in general to agree with the relationship $pv^{1\cdot3} = \text{constant}$, so far as his calculation went, which was very approximately the relationship holding when variable specific heat was taken into account. With this value of the index, however, the figure of 107·5 lb. given near the bottom of page 1254 should be, he thought, 98·7 lb. Perhaps the Author would kindly check it. Possibly he (the Chairman) had made a mistake.

The Author stated that the maximum temperatures, both in the constant-volume and the dual-combustion cycles, were the same for the same weight of fuel burned per lb. of air. Surely that was not quite correct, since in the case of dual-combustion, work had been done at the expense of heat from a to f on Fig. 4 (page 1241), so that the maximum temperature would be less in that case than when the same weight of fuel was burned per lb. of air in the constant-volume cycle.

Dr. W. J. WALKER said that the first point he had noted for reply was Dr. Morley's reference to the continuation of the energy

(Dr. W. J. Walker.)
curves of Fig. 11 up to a temperature of 4,000° C. abs. Actually, of course, such temperatures were not attained in practice, but the figures given by Pier and Bjerrum carried the temperature beyond 3,000° C. Dr. Morley had suggested that he was rather optimistic in looking forward to an overall thermal efficiency of 50 per cent. It should be remembered, however, that this figure, in the Paper, referred to the indicated thermal efficiency, and in his (the Author's) opinion was quite a fair estimate. Assuming that the same relative efficiency could be obtained from an engine working on the maximum efficiency D.C. cycle, 40 per cent efficiency was then probably an underestimate. The remaining 10 per cent, based on the assumption of a 20 per cent efficiency turbine utilizing the exhaust gas energy, could only be expected from a high-power turbine. For lower powers the turbine efficiency might be as low as 10 per cent.

Two closely related factors, to which reference had been made by various speakers, were the mean effective pressure and maximum temperature of any cycle. It was admitted that the temperature at point *f*, Fig. 4, was higher in the D.C. cycle than in the Diesel cycle. The amount of air drawn in, in the D.C. cycle, was represented by the volume V_c, while that of the Diesel engine was V_d. The curve of Fig. 5 gave a maximum efficiency for the D.C. cycle at a compression ratio of 9. At point *f*, however, the temperature of the D.C. cycle would be about 50 per cent higher than in the Diesel cycle. If it were assumed, however, that the same amount of fuel was burned per lb. of air in each case, so that the maximum temperatures would be the same, the maximum efficiency would be found to take place at a compression ratio of 7·5 to 1. The mean effective pressure would, however, be reduced. To get over the high temperature difficulty, the only suggestion he could make was that of water injection. It was certainly the most effective method. Dr. Morley had referred to the fact that efficiency was, after all, not the most important point, with which he quite agreed. The capital cost of an engine mounted up very rapidly as the mean effective pressure diminished, and so did the running costs. Therefore, they ought to aim at high mean effective pressures as well as high efficiencies. The D.C. cycle was essentially a high

mean effective pressure cycle. It could not be denied that if they tried to continue combustion beyond a certain point in the Diesel engine the efficiency was considerably reduced. This was due not so much to the high temperatures as to the thermodynamic disadvantages of the cycle. He would go into this more fully in his written reply.

Mr. Windeler had referred to the fact that many firms who, at one time, used water injection, had given it up on account of trouble arising from oxidation, corrosion, etc. Most of these water-injection devices had, to his (the Author's) mind, been of unscientific type, such as water drips or water drawn in, during the suction stroke, from the water-jackets through various valve devices. If the water were injected as a fine spray, he thought the difficulties would largely disappear. In Professor Hopkinson's well-known work on water injection, the water was forced in, during explosion, in the form of globules, and one had heard very little about corrosion difficulties in these experiments. On the Manchester engine over two hundred tests were carried out last year, and it was used fairly frequently in class work at the present time, but no harmful effects had been noted due to the water injection.

Mr. Hutton had said that commercially his (the Author's) maximum efficiency D.C. cycle did not offer any more prospects than the existing D.C. cycle engines. Of course, he could give no practical evidence that it would, but the theoretical evidence was indisputable.

Professor Gibson had raised the question that perhaps the high efficiency of the normal constant volume cycle in certain cases was due to the forward sloping of the combustion line. To some extent this explained the high efficiencies obtained in high-speed aero-engine work.

Professor Gibson had also raised the question whether the introduction of constant volume combustion was advantageous for an engine working normally under constant pressure conditions. The theoretical evidence certainly indicated that it was.

The Chairman inquired if there were any experimental evidence ?

Dr. Walker replied that he knew of only one case where it had been claimed that it was disadvantageous to burn some of the fuel at constant volume. He had gone into this Paper* and found that the writer backed up his practical conclusions by a theoretical analysis which was based on obviously erroneous assumptions.

Another point raised by the Chairman was the effect of bad cooling upon the efficiency. Perhaps he (the Author) had not made himself quite clear on the matter. Comparing two engines, one with cast-iron and the other with aluminium cylinders of similar dimensions, the volumetric efficiency of the cast-iron cylinder engine was lower, and the brake thermal efficiency was less. Having measured the volumetric and mechanical efficiencies of those two engines, and thus determining the indicated thermal efficiency of each, the latter was invariably found to be about the same in each case. This was the result which he had deduced from his own work.

In conclusion, he desired to thank the Manchester members for their kind reception of his Paper.

The Chairman congratulated the Author upon his lucid explanation of a Paper which was not of a type to be easily read or discussed verbally. It required careful study, in order that full benefit might be obtained from it. He moved a vote of thanks to the Author.

A Vote of Thanks was passed unanimously.

Thanks were also voted to the Chairman for presiding.

Communications.

Mr. Alexander A. Jude wrote that he was rather uncertain about the proposal for the regenerative scheme mentioned by the Author (page 1258). There seemed to be something very vague

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* "Internal Combustion Engineering," 1914, page 286.

about it, possibly due to the scheme not being sufficiently amplified. He would like to know how the Author proposed to get the necessary low back-pressure without an air-pump (or gas-pump), and feared there would not be much change left over the transaction.

The expression " High Efficiency Turbine " was unfortunate, for it conveyed the idea that the Author expected some rather miraculous machine to rescue the scheme from the shadow, if not the substance, of disaster. The writer, therefore, asked what $\frac{\text{B.H.P.}}{\text{Theo. H.P.}}$ efficiency the Author expected under certain conditions he might specify.

Dr. T. B. Morley wrote, in continuation, of his remarks (page 1285), that he had completed and checked his chart, based upon the Author's constants. (*See* Fig. 21, pages 1298–9.)* Working out by its aid the examples given in the Paper, the following were the results obtained :—

Example No. 1.

	—	Pressure P.	Volume V.	Temperature T.	Intrinsic Energy I.
					(heat units).
1	Beginning of compression	14·0	18·0	373	62·4
2	End of compression .	115	4·0	670	116
3	End of combustion .	522	4·0	3,080	695
4	End of expansion . .	78·7	18·0	2,075	420

Work during compression $= I_2 - I_1 =$ 53·6 (in heat units)
Work during expansion $= I_3 - I_4 =$ 275 „ „
Work in cycle . . . . 221·4 „ „

$$\text{M.E.P.} = \frac{221{\cdot}4 \times 1{,}400}{144 \times (18-4)} = 153{\cdot}5 \text{ lb. per sq. in.}$$

Heat supplied $= I_3 - I_2 = 579$

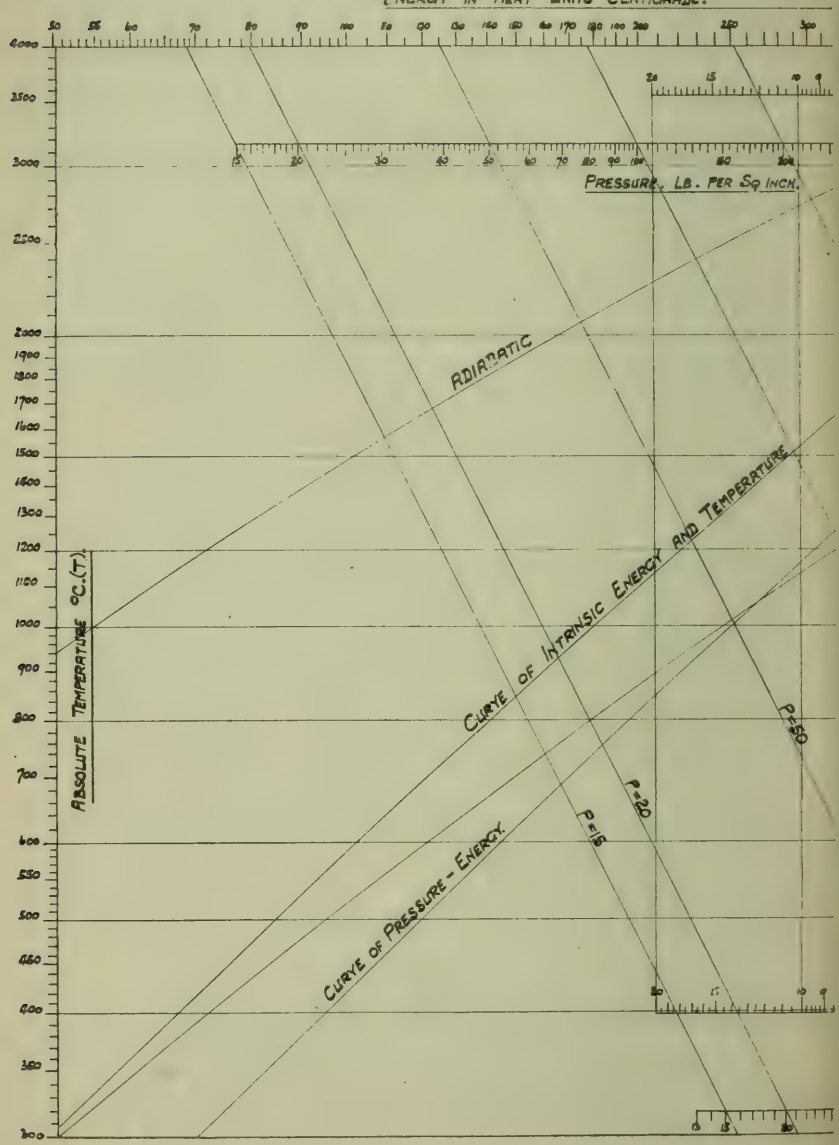
Thermal efficiency $\eta = \frac{221{\cdot}4}{579} = 0{\cdot}383$

* For the method of using the chart, see *Engineering*, 18 December 1914, in which a similar chart is described.

(Dr. T. B. Morley.)

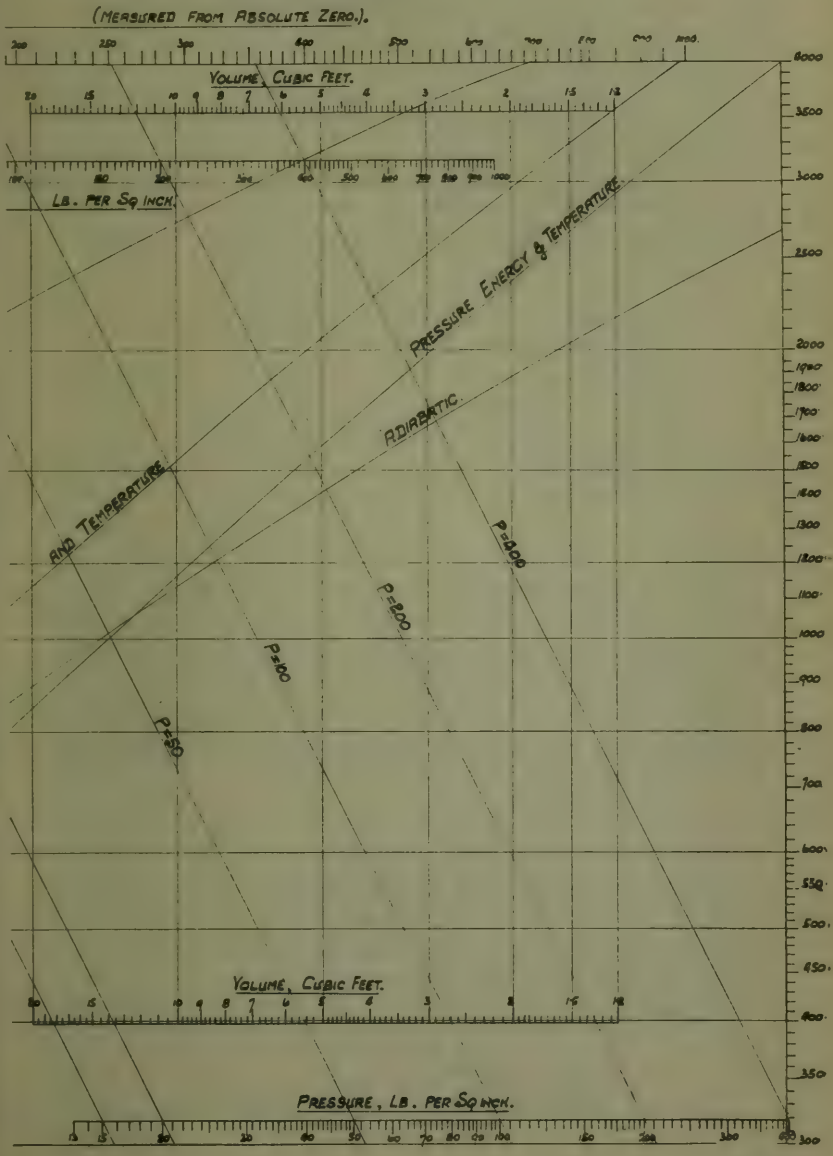
(*Continued on opposite page.*)

FIG. 21.—ENERGY CHART FOR GAS-ENGINE MIXTURES.



(*Continued from opposite page.*)

Based on $\begin{cases} K_v = 0{\cdot}157 + 0{\cdot}0000445\ T. \\ K_\rho = 0{\cdot}2265 + 0{\cdot}0000445\ T. \end{cases}$



(Dr. T. B. Morley.)

Example No. 2.

		Pressure P.	Volume V.	Temperature T.	Intrinsic Energy I.
					(heat units).
1	Beginning of compression	14·7	18·0	386	64·6
2	End of compression .	153	3·33	740	128
3	End of combustion .	515	3·33	2,510	535
4	End of expansion . .	58·8	18·0	1,560	297

Work during compression $= I_2 - I_1 = 63{\cdot}4$ (in heat units)
Work during expansion $= I_3 - I_4 = 238$ „ „
Work in cycle . . . . . 174·6 „ „

$$\text{M.E.P.} = \frac{174{\cdot}6 \times 1{,}400}{144 \times (18{\cdot}0 - 3{\cdot}33)} = 115{\cdot}5 \text{ lb. per sq. in.}$$

Heat supplied $= I_3 - I_2 = 407$

$$\text{Thermal efficiency } \eta = \frac{174{\cdot}6}{407} = 0{\cdot}428$$

The M.E.P. values given by the Author were 138 and 107 respectively. He (Dr. Morley) had checked the chart very carefully and had also calculated the two examples algebraically, obtaining M.E.P.'s of 150 and 116, agreeing closely with the chart.

There was still, therefore, a considerable discrepancy between his results and the Author's, to which he had no doubt the Author would direct his attention.

Baron G. STEINHEIL wrote that he was unable to understand how the formula (1) based on Fig. 4 (page 1241) had been derived. Dr. M. P. Seiliger, formerly Director of Messrs. L. Nobel, Ltd., of Petrograd, had evolved this identical formula on the assumption that the curve *d c b* was an adiabatic compression.*

Strictly speaking, the Diesel cycle, as applied in practice, was

* Journal, Russian Technological Society, 1910.

nothing else than a particular case of a dual-combustion cycle; because when $\frac{pa}{pb} = 1$ we had the constant pressure cycle. Actual tests of engines, especially of those having high piston-speeds (such as used on submarines), showed that at slow revolutions, that is, moderate piston-speeds, the compression $pb = pa = 30$–32 atm., and the burning of fuel followed an isobar, or line of constant pressure. The diagram was then of the conventional Diesel flat-topped type.

When the revolutions were brought higher, that is, at increased piston-speeds, the diagram took the form shown in Fig. 22 and

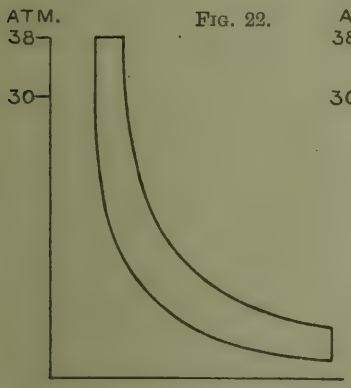


FIG. 22.

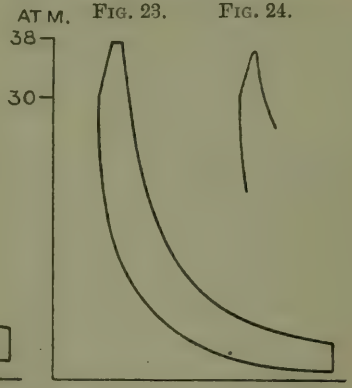


FIG. 23.

FIG. 24.

Fig. 23. The case of Fig. 23 was a burning at variable volume, due generally to a retarded injection. Thus it seemed, that with an increase of speed, the isobaric burning of fuel at a slow rate of combustion got replaced by an explosion at constant or variable volume from 30 atm. to 38 atm., and a very short isobaric burning at a high rate of combustion. In some cases, the isobaric burning did not take place at all, and the diagram became sharp pointed, Fig. 24.

The writer did not agree with the Author in regard to his statement that high compression was the main objection to the use of Diesel engines for motor-car and aero work. With our modern knowledge of steels and alloy metals, the reciprocating parts of such an engine could be made light and strong enough to allow

(Baron G. Steinheil.)

for the high speeds of revolution common in car-work. The question of starters need not be considered, as practically all modern car-engines were provided with starters. It might be mentioned that over ten years ago a V-type 200 b.h.p. 8-cyl. 4-stroke cycle marine Diesel engine was built by Messrs. L. Nobel, Ltd., of Petrograd, for a fast motor-boat. The weight of this engine was 10 kg. per b.h.p.* This figure could be materially reduced now by using modern steels and alloys. The main difficulty of application of the Diesel engine for car and aero work was in the design of a proper pulverizer which, for the sake of simplicity, must be of the solid-injection type. The pulverizer for an engine of this type must of necessity be of such microscopic dimensions and the holes in the fire-plate of such a small bore that machining difficulties would arise to a great extent. The fuel-oil would also have to be very well filtered, as otherwise the pulverizers would get choked at once. Another vital part of such an engine would be the fuel-pump, to which the same arguments would apply.

With reference to the part of the Paper dealing with regeneration, the writer could state that the water injection in certain types of existing oil-engines was the curse of all engineers having to deal with them. Besides complicating the installation by addition of fresh-water tanks (especially undesirable in ships), it led to corrosion of the inside of the cylinders, through the formation of sulphuric acid, it also washed away lubricating oil from cylinder walls, and coated them with deposits of lime and other impurities, bringing running troubles and frequent replacements.

Another way of using the waste heat of exhaust gases for industrial purposes was in the application of this heat to warm up the central heating systems of factories. It might be of interest to the members to know of an actual installation carried out by the writer at the Petrograd Ordnance Works in 1915. The works employed 2,000 hands, the power station consisted of six Diesel engines 1070 b.h.p. total. Each engine was provided with an

* This engine might rightly be claimed to be the lightest Diesel engine in the world yet produced.

ordinary silencer and a water-heater, consisting of a vertical tube cylinder. Either the water-heater and silencer or the silencer only could be connected to the engine exhaust-pipe by means of a by-pass valve. The jacket-water, after leaving the cylinders, was conveyed to the heater and thence along pipes to the radiators in various shops and offices of the works. The water systems of these engines were connected in parallel, so that the temperature of the water in radiators could be regulated irrespective of load, by eliminating one or two of the engines if necessary, to reduce the temperature on a warmer day. A pump was provided to circulate the water through the system. The temperature of the outlet water from cylinders was kept at 80° C., the water returning to the cylinders at 40° C. The temperature of exhaust gases at full load was about 300° C. A certain amount of back pressure (about 0·2 atm.) was observed by means of low-pressure spring indicator diagrams, this fact being due to the restricted passages of exhaust gases through the heater, to avoid undue expansion producing a loss of heat. The fuel consumption of these engines, under working conditions, averaged 190–195 grams per b.h.p. hour.

[*A more detailed Communication by the Writer is preserved in the Library for reference.*]

Professor G. GERALD STONEY, F.R.S., wrote that the main point of interest to him was contained in the proposal made at the end of the Paper to utilize the exhaust heat of the gases by expansion in an exhaust turbine. The introduction of water-injection, as a means of concentrating the waste heat of the engine in the exhaust discharge (that is, the transference of as much as possible of the jacket-heat to the exhaust), was interesting. Assuming the existence of the Author's 40 per cent efficiency D.C. engine with water-injection and 40 per cent exhaust heat, the consequent reduction of temperature of the exhaust gases, together with the increased heat energy available, appeared likely to bring the exhaust gas-turbine within the range of practical consideration. It was for high powers only, however, that one could look for efficiencies in the neighbourhood of 20 per cent for exhaust turbines. For small

(Professor G. Gerald Stoney.)

engine-sets, the conversion of 20 per cent of the exhaust-gas energy into useful work, by means of an exhaust turbine, would hardly be possible at the present stage of development. In any case, however, there appeared to be much to commend the proposal for further investigation.

The Author proposed the D.C. engine for traction purposes. It was well known that one of the main objections to the Diesel engine for such work was its high-compression ratio, with consequent starting difficulties. It had often been proposed for use in road vehicles, its high efficiency apparently being the attraction. The D.C. engine it appeared, however, gave a theoretically higher efficiency than the Diesel, and had a lower compression ratio. The difficulty which appeared at first sight in the adoption of the D.C. cycle, was that of arriving, without undue mechanical complication, at the two distinct stages of combustion.

Dr. W. J. WALKER wrote, in reply to the Communications, that Wimperis' formula for the efficiency of the suction volume expansion C.V. cycle under variable specific heat conditions is—

$$\eta = \eta' \left\{ 1 - \frac{S}{B} (1 - \eta') \left(\frac{T_1 + T_2}{2} \right) \right\}$$

where T_2 = absolute temperature at end of explosion,

T_1 = „ „ „ compression.

Since $\frac{T_2}{T_1} = a$, this becomes

$$\eta = \eta' \left\{ 1 - (1 - \eta') (a + 1) \frac{\lambda T_1}{2} \right\}$$

But $\eta' = 1 - \frac{1}{r^{\gamma - 1}}$

$$\therefore \quad \eta = \eta' \left\{ 1 - \frac{\lambda T_1}{2 r^{\gamma - 1}} (a + 1) \right\}$$

Also $T_1 = T_a r^{\gamma - 1} e^{\lambda T}$

where T_a = absolute temperature at beginning of compression.

$$\therefore \quad \eta = \eta' \left\{ 1 - \frac{\lambda T_a}{2} (a + 1) \right\} \text{ to a first approximation.}$$

Formula (5) in the Paper became the same as this for the C.V. cycle when $\lambda' = 0$.

The following was an example, as requested by Mr. Petter (page 1265), of the use of Fig. 11 in the construction of a Diesel engine diagram. Assuming a mixture strength of $0{\cdot}5 \times 10^6$ ft-lb. per lb. of cylinder contents and a compression ratio of 15, the final compression pressure was found to be 500 lb. per square inch, and the temperature 880° C. abs. At that temperature the constant pressure energy line read $0{\cdot}31 \times 10^6$ ft.-lb. per lb. When combustion was complete, therefore, at constant pressure, the energy would be $0{\cdot}81 \times 10^6$ ft.-lb. per lb. Finding this point on the C.P.E. line, all that was necessary was to follow a line vertically upwards from this point to meet the horizontal line at 500 lb. per square inch abs. The volume was then read off as 2·9 cubic feet at the end of combustion. This gave a value of $\rho = \frac{2{\cdot}9}{1{\cdot}2} = 2{\cdot}42$.

The Author was interested to note Mr. Stern's method of showing, by means of elementary cycles, why the efficiency was a maximum for the D.C. cycle at a compression ratio less than that of the Diesel engine, as he himself had used that method for some time in explaining the point to his students. Mr. Stern stated, however, that when the maximum efficiency D.C. cycle had a constant specific heat efficiency of 60 per cent, the Diesel cycle had one of 58 per cent for the same maximum pressure and the same quantity of heat. This did not appear to be correct. The efficiency of the Diesel cycle under such conditions fell somewhere between 53 and 54 per cent, which was appreciably less than the 60 per cent efficiency of the D.C. cycle. This was on the assumption that by "the same quantity of heat," Mr. Stern meant the same amount of fuel burned per lb. of air.

With reference to Mr. Chorlton's remarks (page 1271) on classification, the practical divisions into which the D.C. cycle might be divided appeared to be:—

(1) Double-aperture injection.
(2) Single-aperture—two injections.
(3) Single-aperture—single injection.

(Dr. W. J. Walker.)

The Blackstone engine was the only one of which the Author was aware, falling into the first division, and the Sabathé engine was probably the earliest type of the second. The de la Vergne and Trinkler-Korting engines were examples of the third, in which might be included also such engines as the Crossley and Vickers solid-injection medium compression type. The C.P. combustion of the two last-mentioned examples appeared to be attained by purposely retarding the rate of fuel injection towards the end of injection.

Mr. Tookey (page 1273) had assumed that the Author's diagrams, plotted as they were up to a maximum m.e.p. of 200 lb. per square inch, were a prophetic forecast of what might be expected in future. Since, however, these were plotted from theoretical calculations, the limit of 200 lb. occurred only as a convenient figure for calculation. Recent values for petrol engine performances were, however, tending very much past the 100 lb. per square inch m.e.p. of gas-engine performance.

It was gratifying to learn from Mr. Hutton's remarks (page 1286) that the theortical result deduced in the Paper that a value of $\rho = 1 \cdot 2$ approx. gave the highest efficiency, was verified by the performances of modern engines working on the D.C. cycle.

Mr. Petrie had referred (page 1290) to the fact that if higher values were given to λ than the Author's value, relative engine efficiencies on variable specific heat greater than 100 per cent were obtained. During the discussion of a Paper * by Professor A. H. Gibson and the Author, giving the results of an extended series of gas-engine tests under different conditions as to engine speed, compression ratio, air/gas mixture, etc., it was suggested by the President that the ratio called the "*Efficiency Ratio*" in the Paper should be changed to "*Relative Efficiency*," as the former expression was generally taken to be the ratio of actual thermal efficiency realized to the thermal efficiency theoretically obtainable with variable specific heat of working fluid. In the Paper in question the "*Efficiency Ratio*" was given as the ratio of the actual thermal efficiency to the *Air Standard Efficiency*. Following upon

* Proceedings I.Mech.E., May 1915.

this suggestion, the Author had since determined the values of a from the indicator diagrams taken in the tests. From these values of a, the efficiency values were determined as given in the Table below, assuming $\lambda = 0{\cdot}000283$. Since the highest efficiency was

Efficiency Ratios.

—		Compression Ratio.								
		5·17			5·70			6·62		
Ratio.	Air Gas.	7	9	11	7	9	11	7	9	11
B.H.P.	R.P.M.									
10	150	85·2	84·4	83·1	82·8	85·7	84·5	83·1	86·4	85·5
	200	81·3	84·4	84·4	82·3	85·6	84·8	83·0	86·6	85·8
	250	81·7	84·5	84·6	81·9	84·7	85·3	82·5	85·4	86·1
15	150	85·3	87·4	85·1	86·1	87·9	86·5	86·4	88·7	87·5
	200	84·4	87·3	86·5	85·5	87·8	86·8	86·3	88·9	87·9
	250	84·5	87·1	86·4	84·8	86·5	87·1	85·5	87·4	87·8
20	150	87·3	89·8	—	88·3	90·3	—	88·5	91·0	—
	200	86·0	89·2	88·4	87·4	89·6	88·6	88·1	90·6	89·7
	250	86·1	89·1	88·3	86·6	88·3	88·9	87·3	89·2	89·7
25	150	88·6	—	—	89·5	—	—	89·8	—	—
	200	87·4	90·5	—	88·5	91·2	—	89·4	92·3	—
	250	87·2	90·1	89·3	87·5	89·6	90·2	88·3	92·8	89·9
30	150	—	—	—	—	—	—	—	—	—
	200	88·4	—	—	89·6	—	—	90·1	—	—
	250	88·2	91·1	—	88·5	90·6	—	89·1	93·8	—

about 94 per cent, these tests indicated that this value of λ could not be far from its actual value.

Professor Gibson had pointed out (page 1292) that the curves of Fig. 9 did not agree very well with his experiments on petrol engines. In such experiments, however, it was exeeedingly difficult to determine accurately the indicated m.e.p., while the brake m.e.p. and efficiency were always affected by the combustion and volumetric efficiencies. In tests under different air/petrol mixtures the two latter factors were not constant. The curves of Fig. 9, however, involved the assumption that they were constant. These curves were not meant for comparison of different tests on any one engine but for comparison of the best performances possible for different engines.

Professor Gibson's figure of 98·7 lb. per square inch abs. (as against the Author's value of 107·5 lb. per square inch abs. at the end of a compression ratio of 4·5) obtained from the formula pv^m = const. where $m = 1{\cdot}3$, did not appear to be justified, since the mean value of m from 18 to 4 cubic feet is 1·37, while from 4 to 1 cubic feet it is only 1·28.

For this same final compression pressure Dr. Morley gave 115 lb. per square inch abs. (page 1297), but the Author by graphical solution of the equation $pv^m e^{\lambda\tau}$ = const. had verified his own value of 107·5 lb. per square inch abs. to be very nearly correct. This accounted for the discrepancy between Dr. Morley's and the Author's figures for m.e.p. Dr. Morley's method of determining both m.e.p. and efficiency depended upon calculation involving values, such as final compression pressure and temperature, derived from his chart. Since the work done during compression was affected by his final compression pressure, the importance of correct values for the latter was obvious. In connexion with the drawing up of the chart of Fig. 11 and the other auxiliary diagrams in Figs. 6–10, the Author would point out that the labour involved was considerably lessened by the use of the efficiency formula (5) and by the m.e.p. formulæ given in the Appendix (page 1310).

The regeneration scheme of the Paper had been subjected to a

good deal of criticism, probably on account of its brevity and absence of explanatory matter. The Author inserted this view on regeneration by request, and the brevity of the paragraph was due to the limited time at his disposal to go into details. He was still of opinion, however, that regeneration along the lines suggested was better practically, and possibly theoretically, than that of any scheme involving external steam generation or the use of hot-air regenerators. The maintenance of high temperatures inside the cylinder of an engine, as in the Still engine, and in any scheme involving hot-air regeneration, tended seriously to diminish m.e.p.'s by reducing volumetric efficiencies. To increase the m.e.p. in any cycle it was necessary to burn more fuel, and consequently to increase the temperature. This reacted by reducing the volumetric efficiency. There appeared to be no way out except either that of lowering the m.e.p. by reducing the amount of fuel burned or by better cooling. To tackle seriously and solve the difficulties which cropped up in the application of internal water cooling would go a much longer way towards increasing the value of the internal-combustion motor as an economic and high m.e.p. prime mover, than that of complicated water-jackets and water or oil-cooled pistons. The difficulties to be overcome did not appear to be in any way greater.

Professor Stoney had pointed out that such high over-all efficiencies as 20 per cent were not to be expected from low-power turbines. The Author had principally in mind such multi-cylinder engines of from 200 to 500 h.p. as were used in aero work when he gave the example at the end of his Paper, and the following more detailed figures were given in amplification of what he had given there. Assuming such an engine of 300 h.p. working on a maximum efficiency D.C. cycle of 40 per cent efficiency, the power available in the exhaust gases at the end of expansion in the engine cylinder would be of the order of 33 per cent of the engine power, assuming the turbine to expand these gases down to atmospheric pressure only. Mr. Jude (page 1297) appeared to have thought that expansion below this pressure was intended. The power available for development in the turbine was therefore

(Dr. W. J. Walker.)

100 h.p. Assuming a hydraulic efficiency of 60 per cent, this meant 60 h.p. given out by the turbine. Hence the over-all efficiency would be $\frac{360}{300} \times 40 = 48$ per cent. The hydraulic efficiency of 60 per cent was still high and could only be obtained at present with turbines above 500 h.p. For powers in the neighbourhood of 100, the hydraulic efficiency was about 55 per cent.

The Author was interested to hear from Baron Steinheil (page 1300) that formula (1) had already been obtained by Dr. Seiliger. He (the Author) first published it in *The Automobile Engineer*, in January 1918. The formula was based on the assumption that *d c b* was an adiabatic compression line. Referring to page 1241, it would be seen that the formula was there stated to be that for "suction volume expansion," that is, when expansion finished at the same volume as compression began. The extended analysis for the D.C. cycle illustrated in Fig. 4 (page 1241) was not given in the Paper, but was to be published shortly in a Paper read before the Manchester Literary and Philosophical Society in November last.

APPENDIX.

The Variable Specific Heat Relationship between Maximum Pressure and Mean Effective Pressure in the Variable Volume Cycle.

The Mean Effective Pressure is given by

$$p_m = \eta_s \times \frac{\text{Heat given}}{\text{Working volume}}$$

where η_s = variable specific heat efficiency of the cycle. This is given by the constant specific heat efficiency multiplied by the factor

$$1 - \frac{\lambda T}{2}(a + \rho)$$

$$\therefore p_m = \eta_s \frac{(T_2 - T_1)\left\{B + \frac{S}{2}(T_2 + T_1)\right\} + R\left(T_1 + \frac{T_2}{\rho}\right)\frac{(\rho - 1)}{2}}{\frac{RT}{p} - \frac{RT_1}{p_1}}$$

where T_2 = absolute temperature at end of combustion

T_1 = " " " compression

T = " " at beginning of compression

$$\therefore \quad p_m = \eta_s p_1 \frac{(\alpha\rho - 1)\left\{1 + \frac{\lambda T}{2} r^{\gamma-1}(\alpha\rho + 1)\right\} + (\gamma - 1)\frac{(\alpha+1)(\rho-1)}{2}}{(\gamma - 1)(r - 1 - \lambda d)}$$

where p_1 = final compression pressure

and $$d = \left(1 - \frac{1}{r^{\gamma-1}}\right) T = \eta'_v T.$$

Since λ is small this may be written—

$$p_m = \eta_s p_1 \frac{\alpha\rho - 1}{(\gamma - 1)(r - 1)}\left[1 + \frac{\lambda T}{2}\left\{(\alpha\rho + 1) r^{\gamma-1} + \frac{2\eta'_v}{r-1}\right\}\right] + \eta_s p_1 \frac{(\alpha+1)(\rho-1)}{2(r-1)}\left\{1 + \frac{\lambda T \eta'_v}{r-1}\right\}.$$

The corresponding relationship for the Dual Combustion Cycle is obtained as follows :—

$$p_m = \eta_d \frac{(T_1 - T_o)\left\{B + \frac{S}{2}(T_1 + T_o)\right\} + (T_2 - T_1)\left\{A + \frac{S}{2}(T_2 + T_1)\right\}}{\frac{RT}{p} - \frac{RT_o}{p_o}}$$

where η_d = variable specific heat efficiency as given by formula (2) in the Paper.

T_2 = absolute temperature at end of constant pressure combustion.

T_1 = " " " " " volume "

T_o = " " " " " compression.

T = " " " beginning of compression.

$$\therefore p_m = \eta_d p_o \frac{(\alpha - 1)\left\{1 + \frac{\lambda T}{2}(\alpha + 1) r^{\gamma-1}\right\} + \gamma\alpha(\rho - 1)\left\{1 + \frac{\lambda T}{2}\left(\frac{\alpha\rho + 1}{\gamma} r^{\gamma-1}\right)\right\}}{(\gamma - 1)(r - 1 - \lambda d)}$$

where p_o = pressure at end of compression.

This, to a first approximation gives—

$$p_m = \eta_d p_o \frac{\alpha - 1}{(\gamma - 1)(r - 1)}\left\{1 + \frac{\lambda T}{2}\left[(\alpha + 1) r^{\gamma-1} + \frac{2\eta''_v}{r-1}\right]\right\} + \eta_d p_o \frac{\gamma\alpha(\rho - 1)}{(\gamma - 1)(r - 1)}\left\{1 + \frac{\lambda T}{2}\left[\frac{\alpha(\rho+1)}{\gamma} r^{\gamma-1} + \frac{2\eta'_v}{r-1}\right]\right\}.$$

MEMOIRS.

Joseph Adamson was born at Shildon, Durham, on 22nd May 1843, and in 1858 was apprenticed to his uncle, Daniel Adamson, of Dukinfield, with whom he continued until 1873. He started as a boilermaker at Hyde in partnership with the late Mr. Henry Booth, in September 1874. In September 1887 the partnership was dissolved, and in April 1902 his two sons, Mr. Daniel and Mr. Harold Adamson, joined him in partnership. The business, starting in a small way, gradually grew, necessitating extensive additions. In 1884 he introduced hydraulic plate flanging for the general boiler trade, and this became a very important part of the firm's operations. Ten years later he commenced the manufacture of electric travelling cranes in which an extensive business is done, and the firm was the first in the district to adopt electric motive power, the electricity being generated at the works. He was a director of several companies, and some years ago was managing director of the North Lincolnshire Iron Co. He was one of the oldest Members of the Institution, having been elected a Member in 1871, on the Council of which his elder son, Daniel, is a Member, In 1908 he became President of the Manchester Association of Engineers; he was also a Member of the Iron and Steel Institute, and of the Institute of Metals. He was a man of strong personality, characterized by fearlessness and directness of expression, and was always ready to assist those who appealed to him for guidance. His death took place after a brief illness at his residence in Hyde, on 14th August 1920, at the age of seventy-seven.

Joseph John Butcher was born in Liverpool on 30th August 1849. After serving a short time in the works of Smith and Carvey, Liverpool, he was engaged for three years in superintending the manufacture of furnace-feeding apparatus at the works of Clarke,

Chapman and Co., Gateshead-on-Tyne, and then started in practice as a consulting engineer. During this period he gave much attention to the development of the gas-engine, and contributed many articles to the technical press. In 1889 he went to America, where he devoted much time to various inventions; his later years were largely occupied with the construction of an aeroplane, of quite a different type from those then in use. His death took place at Victoria, B.C., in November 1919, at the age of seventy. He became a Member of this Institution in 1884.

Christopher Geddes was born at Hartlepool in 1847, and was educated at Castle Eden. In 1864 he entered the works of Messrs. Thomas Richardson and Sons, Hartlepool, as an apprentice, and served five years, rapidly becoming one of the leading guarantee engineers for the firm. Subsequently he entered the employment of the late Mr. William Esplen, of Liverpool, as superintendent engineer, and was responsible for the construction of a large number of light-draft vessels in South America. After completing this work, he returned to England and was appointed technical engineer for the Leeds Forge Co., which post he held for some time. He then started in practice in Liverpool as consulting engineer and naval architect, and carried out much important work for many of the leading steamship companies. His death took place at Huyton, Liverpool, on 21st October 1919, at the age of seventy-two. He became a Member of this Institution in 1888; he was also a Member of the Liverpool Engineering Society and of the North-East Coast Institution of Engineers and Shipbuilders.

Harold Percy Goddard was born in London on 7th November 1874. After leaving school he became a student at the Finsbury Technical College, and then served an apprenticeship with Messrs. Rait and Gardiner, marine engineers, at the Royal Albert Docks, London. In 1896 he went to Calcutta, and was engaged there as engineering assistant to Messrs. Marshall, Sons, and Co., in the erection of plant at various tea factories. Returning home in 1901, he was employed by Messrs. Price and Reeves on the construction of the

Charing Cross and Hampstead Tube, and then went to Pernambuco where he was engaged on drainage work for Sir Douglas Fox and Partners. Subsequently he joined the staff of Messrs. Pearson and Co., at Para, Brazil, for dredging work, and for a short time was engaged by the Leopoldina Railway Co. on construction work. He returned to England in 1914 and joined the U.P.S. at Epsom and other camps, being invalided out after two years. He was then engaged as engineer at an explosives factory at Grays, Essex. In February 1917 he went to the Federated Malay States as engineer in erecting a rubber factory, and in the following year he joined the F.M.S. Railway as construction engineer. His death took place at Penang on 28th February 1920, at the age of forty-five. He was elected an Associate Member of this Institution in 1912.

EBENEZER HALL-BROWN was born at Greenock on 7th April 1862, and served his apprenticeship with the Fairfield Shipbuilding Co., afterwards joining Messrs. Richardson and Sons, Hartlepool, as head of their Scientific Department. In 1892 he went into partnership, establishing the firm of Hall-Brown, Buttery and Co., Glasgow, which built a large number of engines for passenger and cargo steamers, etc. In 1901 he became engineering partner in the firm of Rodger and Co., Glasgow, and in 1912 rejoined Messrs. Richardsons Westgarth as General Manager. This position he held to the time of his death, which took place at Middlesbrough on 13th May 1920, at the age of fifty-eight. He became a Member of this Institution in 1889. He was a Member of the Institution of Civil Engineers, of the Institution of Naval Architects, Past-President of the Institution of Engineers and Shipbuilders in Scotland, and a Member of Council of the North-East Coast Institution of Engineers and Shipbuilders.

HAMMERSLEY HEENAN was born at Birr, Ireland, on 5th January 1847, and received his early education at Parsonstown. At the age of seventeen he entered the service of the East Indian Railway, and subsequently was appointed an assistant engineer in the Public Works Department. After working for about fifteen years in that

position, he was detailed for service in the Bawhlpore State, where he designed the palace for the ruler of that State. Ultimately he was appointed chief engineer to the P.W.D., but was obliged to decline owing to his health not permitting him to remain in India. In 1880 he returned to England, and purchased the works of Messrs. Woodhouse and Co., Newton Heath, Manchester, and on the retirement of Mr. Woodhouse, he took into partnership a former colleague of his in India, Mr. J. Froude, thus founding the firm of Heenan and Froude, of whom Mr. Heenan was chairman and managing director until his retirement in 1918. For some time they confined their activities to bridge-building and structural iron and steel work. Among the undertakings carried out may be mentioned the Blackpool Tower, and bridges for many of the English Railways. The firm also supplied and erected material for the harbour of Rangoon. Works were also started in Birmingham in the "Eighties," where many specialities were developed, including the Tower Spherical Engine, which he described in a Paper in the Proceedings, 1885, page 96. Owing to the accommodation proving insufficient, additional works were taken at Worcester for the manufacture of air-filters and coolers, oil and water coolers, refuse destructors, refrigerating machinery, etc., the conception and design of most of these being due almost entirely to Mr. Heenan. During the War, he rendered great service to the Government in the manufacture of munitions. He was a Justice of the Peace for the County of Denbigh. His death took place in London on 17th June 1920, at the age of seventy-three. He became a Member of this Institution in 1875.

Charles Hopkinson, the third son of the late Mr. Alderman John Hopkinson, M.I.Mech.E., was born in Manchester on 16th November 1854. He was educated at the Owens College, Manchester, and joined his father in the old-established mechanical engineering business of Wren and Hopkinson; and after his father's retirement from the firm in 1881, he continued with him in practice as a Consulting Engineer. Later on, after his father gave up active work, he entered into partnership with his eldest

brother, the late Dr. John Hopkinson, F.R.S., Member of Council, I.Mech.E., and in conjunction with him became responsible for many large electric tramway and lighting schemes, including the Leeds tramways and the Newcastle tramways. After the death of his brother in the Alpine accident of 1898, he took into partnership his nephew Bertram, subsequently Professor of Engineering at Cambridge, and his brother's assistant, the late Mr. E. Talbot, and the firm became Hopkinsons and Talbot. He became a Member of this Instititution in 1885 and acted as Honorary Local Secretary at the Manchester Summer Meeting of 1894. He contributed a Paper on "Pumping Plant for Condensing Water" at the Newcastle Meeting of 1902. He was also a Member of the Institution of Civil Engineers and joint author with his partners of a paper on "Electric Tramways" 1902, in which the Leeds and Newcastle systems are described.

He was a director for many years of the Carnforth Iron Co.; and of the Mazopil Copper Co., and was Chairman of the Sinai Mining Co., mining and working large deposits of manganese iron ore in the Sinai Peninsula.

He gave much of his time disinterestedly to public work, and for some years was an Alderman of the Lancashire County Council. As Chairman of the Building Committee of the Manchester Royal Infirmary from 1904 until its opening by King Edward in 1909, his ripe experience and judgment were invaluable in the construction of the large new hospital of 600 beds. His death took place in Cambridge, after a brief illness, on 5th September 1920, in his sixty-sixth year.

John Kirkaldy was born in London in 1853, and was educated at Mill Hill School. He served an apprenticeship at his father's works in the West India Dock Road, London, and quite early took over the management of the business, becoming a partner in 1880. Under his direction the firm played a prominent part in introducing fresh-water distilling plant for use on board ship. The firm also designed and made plant in connexion with the Ashanti Campaign, and similar apparatus was supplied by them in 1883 and 1885 for the

Egyptian Campaign. He introduced a system of using live steam for feed-heating on shipboard. His death took place at Hendon on 7th August 1920, at the age of sixty-seven. He became a Member of this Institution in 1884; he was also a Member of the Institution of Civil Engineers.

Edward Alfred McCallum was born in Russia on 16th March 1874. He was educated at the Royal Grammar School, Lancaster, and at the Owens College, and served his apprenticeship at the works of Messrs. Mather and Platt, Salford. When the Boer War broke out he volunteered in the Royal Engineers, and served during the War. He then went to Russia and worked in Baku as an oil engineer, but left owing to the massacres that took place in September 1905. He next joined the staff of the Russian Westinghouse Electric Co., as superintendent of the electric power installation of the St. Petersburg tramways, and then returned to Baku to take up the position of assistant general manager on the oil-fields. In 1909 he went to Maikop Oil-Fields to take charge on behalf of Bewick, Moreing and Co., and returned to England two years later to act as London representative for an American Oil-Well Engineering Co. In 1915 he offered his services to the War Office, and was sent to Russia on a special mission. Owing to the severity of the climate his heart became affected, and he was very ill for several months. Later he was ordered to Switzerland, but the journey was too trying for his health, and he died in Geneva on 4th February 1919, in his forty-fifth year. He became an Associate Member of this Institution in 1904, and a Member in 1913.

Anthony Patterson was born in Cumberland in November 1843, and served an apprenticeship of six years in the works of the London and North Western Railway at Wolverton. He was then engaged in the Company's drawing-office for four years, and, after a short time spent at Messrs. Sharp, Stewart's works, he became inspector for Mr. Fairlie, of the Avonside Engine Works, Bristol. Subsequently he became manager for Messrs. Chapman and Sutton, Limehouse, for four years, and later was connected with the

Pulsometer Engineering Co. He then left to take charge of the Ulverstone Foundry, near Barrow-in-Furness, and on the sale of the business he became chief draughtsman with the Dowlais Iron Co. Here he reconstructed the coal washery and extended the Bessemer rail mills and banks. He was also responsible for the construction of the blast-furnace plant at the Cardiff Works of the same firm, and in 1895 became chief engineer of the plant at Cardiff. This position he held until December 1918, when he resigned owing to failing health. His death took place on 14th June 1920, at the age of seventy-six. He became a Member of this Institution in 1881.

Ernest Alfred Rankin was born on 2nd March 1872. His scholastic training was received at Uxbridge Grammar School, which was followed by a five-years' apprenticeship in the shops of Messrs Plenty and Son, marine engineers, Newbury. In 1894 he entered the employment of the Royal Mail Steam Ship Co. as 6th Engineer, and in the following year he obtained experience as outside fitter in the docks. Subsequently he was engaged as draughtsman with Messrs. E. S. Hindley, of Bourton, Dorset, and other firms. During the War he worked for the Ministry of Munitions and the Trench Warfare Department, his headquarters being at Bristol. His health, however, was not robust enough to endure the hard work which necessitated much travelling, and his death took place from heart failure, after a short illness, on 22nd February 1919, in his forty-seventh year. He was elected an Associate Member of this Institution in 1902.

John Richardson, J. P., was born in Lincoln on 23rd October 1841. At the age of fourteen he was apprenticed to Messrs. Clayton and Shuttleworth, of Lincoln, and in 1864 he joined the firm of Messrs. Robey and Co., Ltd., of the same city, as a draughtsman, having entire charge of the drawing-office. In 1865 the firm was changed into a private partnership, and in 1874 he became one of the three managing partners. On the conversion of the firm again in 1893 to a limited company,

he was appointed one of the two managing directors, which position he held until his retirement in 1904. During his connexion with the firm he brought out many improvements in engine construction. In 1870 he designed and constructed a road steamer with rubber tyres, and three years later an automatic valve-gear for portable engines; and at the Lincoln Summer Meeting in 1885 he read a Paper on the "Robey Semi-Portable Engine." He also brought out many other devices connected with valve-gears and governors. After retiring from the firm, he practised as a consulting engineer and took out several more patents. His death occurred at Lincoln on 23rd April 1920, in his seventy-ninth year. He became a Member of this Institution in 1873; he was also a Member of the Institution of Civil Engineers.

James Blackwood Rodger was born at Govan, Glasgow, on 18th April 1885. He received his early education at the Bellahouston Academy and the Glasgow High School, and then served an apprenticeship of seven years with the firms of Ross and Duncan, D. and W. Henderson, and John McNeil and Co. During the greater part of this time he also studied at the Glasgow Technical School. In 1908 he went to the Barbados to take up the position of works manager to the firm of John Blackwood, Ltd., shipbuilders and engineers, and held this position until his death, which took place on 22nd December 1919, in his thirty-fifth year. He was elected an Associate Member of this Institution in 1910.

James Scott was born at Kirk Ormes, Cumberland, in 1850. He served an apprenticeship of eight years, five of which were spent in the locomotive shops of the North Eastern Railway at Darlington, and three years in the Springfield Iron Works of Mr. William Barningham. He then went to the Consett Iron Works, Co. Durham, shortly afterwards becoming chief engineer of the Company. During this period he carried out all the rebuilding of their blast-furnaces, and designed and constructed the existing plate- and rolling-mills and the steel plant, making them at that time one of the most up-to-date works in the country.

His death took place unexpectedly at Fenham, Newcastle-on-Tyne, on 13th May 1920, at the age of seventy. He became a Member of this Institution in 1886.

Arthur John Tassell was born at Tonbridge on 12th September 1876, and received his early education locally. In 1892 he began an apprenticeship at the Tonbridge Running Sheds of the South Eastern Railway, subsequently completing it at the Company's Ashford works and drawing-office. In 1901 he was employed in the drawing-office of the Hyde Park Locomotive Works, Glasgow, and in the following year became chief locomotive draughtsman of the North Staffordshire Railway, Stoke-on-Trent. This position he held until 1916, when he was appointed locomotive works manager, and subsequently was engaged in the production of munitions during the War. His death took place at Stoke-on-Trent, on 16th December 1919, at the age of forty-three. He became a Member of this Institution in 1919.

William Howard Taylor was born at Oldham on 11th September 1882, and was educated at local schools. He served an apprenticeship of five years with Messrs. Ferranti, Ltd., of Hollinwood, and for a short time was a draughtsman at the works of Messrs W. H. Allen, Son and Co., Bedford. He next became assistant to the manager of Messrs. Browett, Lindley and Co., Patricroft, and to the Hudson Economiser Co., Manchester, and in 1908 joined the staff of the National Boiler and General Insurance Co., Manchester, representing the Company in various parts of the country. In 1916 he was appointed manager to the Manchester office of Messrs. Peter Brotherhood, Ltd., of Peterborough, which position he held until his death. The latter occurred during a holiday, when he was accidentally drowned at Bolton Abbey in trying to cross a stream, on 22nd June 1920, in his thirty-eighth year. He was elected an Associate Member of this Institution in 1913.

Charles Nicholas Eves Walke was born in 1867, and

was educated privately. He served his apprenticeship in H.M. Dockyard, Bombay, and was engaged as draughtsman during a portion of the time. He then became assistant engineer on H.M. Telegraph Steamer "Patrick Stewart," and in 1889 entered the mercantile marine as chief engineer on various steamers. In 1891 he superintended the erection of the Madura Mills, S. India, for Messrs. A. F. Harvey, and then became engineer for the same firm, which post he held until 1895. In May of that year he was appointed Inspector of Steam-Boilers and Prime Movers for the Bombay Presidency, and remained in the service of the Government until his death, which took place after a short illness, on 10th July 1919, in his fifty-third year. He became a Member of this Institution in 1898.

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Davidson, A. E., Lt.-Col., D.S.O., R.E., appointed Member of Council, 957.—Remarks on Sterilization of Water by Chlorine Gas, 1173.

Davies, H., elected Associate Member, 588.

Davies, P. G., Lt.-Col., C.M.G., R.A.O.C., elected Member, 1199.

Davis, J. S., elected Graduate, 1201.

Davison, E. L. P., elected Associate Member, 958.

Davison, J. W., M.B.E., elected Member, 1199.

Day, A. O., elected Associate Member, 588.

Deacon, F. E., elected Graduate, 589.

DEAN, F., elected Member, 957.
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DE LISLE, G., elected Member, 1199.
DERHAM, A. C., elected Associate Member, 590.
DEWRANCE, Sir J., K.B.E., Remarks on alteration of Articles of Association, 970.—Moved Vote of Thanks to President for Address, 1073.
DIAMOND, E. L., elected Graduate, 959.
DICKIN, G. W., elected Associate Member, 588.
DIMMOCK, G. F., elected Graduate, 589.
DINNER, Lincoln, 777.
DOLBY, E. R., Remarks on alteration of Articles of Association, 971.
DONALDSON, A. J., elected Graduate, 591.
DOOLE, E., Lieut., elected Associate Member, 958.
DOUGLAS, R., elected Graduate, 1201.
DOWLING, R. J., elected Associate Member, 588.
DREW, E. A. H., elected Member, 587.
DRUMMOND, W. J., elected Associate Member, 588.
DRYBURGH, A. P., Associate Member transferred to Member, 959.
DUCKERING, R., Waterside Works, Lincoln, 799.
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DUNK, N. A., Lieut., R.A.O.C., elected Associate Member, 588.

EDMONDSON, R., elected Associate Member, 1200.
ELBOURNE, E. T., Remarks on the Human Factor in Industry, 1225.
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EMBLETON, C. A., Associate Member transferred to Member, 591.
EMERY, J. I., Associate Member transferred to Member, 591.
EVANS, A. G., elected Associate Member, 588.
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Fearn, J., Remarks on the Human Factor in Industry, 726.
Fenner, A. C., elected Graduate, 589.
Fiddes, J. S., elected Graduate, 1201.
Finney, S. H., elected Associate Member, 1200.
Firmin, F. W., elected Associate Member, 958.
Flanders, R. L. H., elected Associate Member, 958.
Fleming, F. A., M.B.E., elected Member, 587.
Forder, E., elected Associate Member, 958.
Forsyth, R., Remarks on Sterilization of Water by Chlorine Gas, 1181.
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Fowler, Sir H., K.B.E., Remarks on Road Transport by Steam-Vehicles, 662.
Fox, C. E., elected Associate Member, 590.
Fox, S. A., Associate Member transferred to Member, 1202.
Francis, W. E., elected Associate Member, 590.
Frankau, G. N., Associate Member transferred to Member, 959.
Franklin, A. C., elected Associate Member, 590.
Fraser, J. S., elected Member, 587.
Frodingham, Excursion at Lincoln Summer Meeting, 779.—Ironstone Mines, 814.
Fuller, A. H., elected Graduate, 589.
Fyffe, J. C., elected Associate Member, 958.

Gadsden, R. F., elected Associate Member, 588.
Gainsborough, New Power-Station, 765.—Excursion at Lincoln Summer Meeting, 780.
Gallinagh, J. P., elected Member, 1199.
Gearing, S. J., elected Graduate, 589.
Geddes, C., Memoir, 1314.
Gemmell, A. R., elected Associate Member, 1200.
Gibson, A. H., Remarks on Internal-Combustion Engine Development, 1279, 1292, 1296.
Giddings, H. C., elected Graduate, 1201.

GILMORE, E. F. G., elected Associate Member, 958.
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GLOVER, A. W., elected Member, 957.
GODDARD, H. P., Memoir, 1314.
GODDARD, J. A., elected Associate Member, 958.
GOMERSALL, L. A., elected Associate Member, 1200.
GORVIN, S. E., elected Associate Member, 590.
GOW, W., Associate Member transferred to Member, 1202.
GOWRING, H. J., elected Graduate, 591.
GRANTHAM, L. R., elected Associate Member, 588.
GRAY, E. H., elected Member, 587.
GREEN, E. S., elected Graduate, 589.
GREENLAND, G. W., elected Graduate, 589.
GREGORY, C., elected Graduate, 589.
GREGSON, W., Major, R.E. (T.), elected Associate Member, 1200.
GRIFFITH, A. C., elected Graduate, 589.
GROOME, S. F., elected Member, 587.
GRUGEON, P., Lieut., R.A.S.C., elected Associate Member, 1200.
GRUNDY, W. E., elected Associate Member, 958.

HAIGH, B. P., M.B.E., *Paper* on Prism-Hardness, 891.
HALE, K. O., elected Member, 587.
HALL, T., elected Associate Member, 588.
HALL, W. E., elected Associate Member, 1200.
HALL-BROWN, E., Memoir, 1315.
HALLIDAY, M., Associate Member transferred to Member, 959.
HALSALL, J. J., elected Member, 957.
HAMERSLEY, H. St. G., Major, R.A.S.C., elected Associate Member, 588.
HANCOX, J. G., elected Associate Member, 588.
HAND, T. W., elected Member, 1199.
HANMAN, J. L., elected Graduate, 1201.
HARDING, W. C., elected Associate Member, 588.
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HARPER, H. J., elected Graduate, 959.
HARRIS, F. P., elected Associate Member, 958.
HARRIS, F. W., elected Associate Member, 588.
HARRISSON, F. G., elected Associate Member, 588.
HART, A., elected Associate Member, 958.
HART, E., elected Associate Member, 588.
HARVEY, G. B., elected Associate Member, 1200.
HAWARD, F. B., elected Associate Member, 1200.
HAWKES, C. J., Eng. Comm., R.N. (ret.), elected Member, 1199.
HAWKINS, A. H., elected Graduate, 959.
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HAYWARD, W. C. G., elected Associate Member, 588.
HEAD, E. W., elected Member, 1199.
HEAYS, H. C., elected Associate Member, 588.
HEBBLETHWAITE, A. C., elected Associate Member, 590.
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HESKETH, J., elected Associate Member, 588.
HEY, I., elected Graduate, 589.
HIAM, R. W., elected Member, 587.
HIGSON, F., elected Associate Member, 590.
HILL, H. P., Remarks on Sterilization of Water by Chlorine Gas, 1179, 1180, 1182, 1189.
HILL, S., Captain, R.E. (T.F.), elected Associate Member, 588.
HILLHOUSE, J. P., Associate Member transferred to Member, 591.
HINES, A. E., elected Graduate, 589.
HINES, S. H , elected Associate Member, 1200.
HJORT, V., Remarks on Sterilization of Water by Chlorine Gas, 1166.
HODGSON, J. L., Remarks on Coefficient of Discharge of Nozzles, 1018.
HOLDEN, E., Remarks on the Human Factor in Industry, 1222.
HOLMSTROM, J. E., elected Graduate, 959.
HONIBALL, C. R., Remarks on Marshalls' Power Station, Gainsborough, 774.
HOPKINS, E. C., Associate Member transferred to Member, 591.
HOPKINS, G. A., Associate Member transferred to Member, 591.

HOPKINS, W. H., elected Member, 1199.
HOPKINSON, C., Memoir, 1316.
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HOWLETT, H. R., elected Member, 587.
HOWSIN, C. G., elected Member, 587.
HUDSON, N., Major, D.S.O., R.A., elected Member, 1199
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HUNT, F. J. A., elected Graduate, 959.
HUTSON, F. C., elected Graduate, 589.
HUTTON, J., Remarks on Internal-Combustion Engine Development, 1286.
HYAMS, C. M., elected Graduate, 959.
HYAMS, G. F., elected Graduate, 959.
HYDE, L., elected Associate Member, 1200.
HYDE, R. R., Remarks on the Human Factor in Industry, 1215.

INDUSTRY, The Human Factor in, *Paper* by A. Ramsay, 709.
INGHAM, C. W., elected Associate Member, 590.
INGRAM, H. W., elected Associate Member, 1200.
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INNES, J. W., elected Graduate, 1201.
INNES, R. K., elected Graduate, 589.
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IRONSIDE, M., elected Associate Member, 958.

IRWIN, H., elected Graduate, 589.

IYER, V. G., elected Associate Member, 588.

JACKSON, A. N., elected Graduate, 1201.

JACKSON, W. A., elected Associate Member, 958.

JAMES, G. Ll. D., elected Member, 587.

JARVIS, Capt. A. C., Remarks on Sterilization of Water by Chlorine Gas, 1191.

JARVIS, E. J., elected Associate Member, 588.

JARVIS, H., elected Graduate, 589.

JEBOULT, W. A., elected Member, 587.

JEFFERSON, F. H., Eng. Lieut., R.C.N., elected Associate Member, 588.

JEFFES, R., elected Associate Member, 958.

JENNINGS, M., elected Associate Member, 588.

JENNINGS, R. R., elected Graduate, 589.

JOHNSON, L., elected Associate Member, 958.

JONES, D. C. H., elected Graduate, 589.

JONES, E. W., elected Member, 1199.

JONES, L. A., Associate Member transferred to Member, 959.

JONES, R. A. W., elected Graduate, 959.

JONES, W. A., elected Associate Member, 958.

JOYCE, H., elected Member, 587.

JUDE, A. A., *Paper* on the Coefficient of Discharge of elementary Nozzles, 977.—Remarks thereon, 1028 :—on Internal-Combustion Engine Development, 1296.

JUMP, P., elected Associate Member, 958.

KENWORTHY, A. R., Major, elected Member, 587.

KING, G. B., elected Graduate, 591.

KING, H. J., elected Associate Member, 588.

KINGDOM, R., elected Associate Member, 958.

KINGHAM, G. P., elected Graduate, 959.

KIRKALDY, J., Memoir, 1317.

Knaggs, F. T., elected Graduate, 959.
Kyte, G. W., elected Graduate, 589.

Langford, C. G., elected Associate Member, 588.
Langley, A., elected Associate Member, 588.
Latham, E. J., elected Graduate, 589.
Lawler, J. R., elected Associate Member, 588.
Layton, T. W., elected Associate Member, 588.
Legat, E. S., elected Associate Member, 588.
Legros, L. A., O.B.E., Remarks on Recent Excavator Practice, 631:—on Road Transport by Steam-Vehicles, 666.—Seconded Vote of Thanks to President for Address, 1074.
Leicester, H. L., elected Associate Member, 1200.
Le Roy, G. J. G., elected Graduate, 959.
Levett, J. V., elected Associate Member, 1200.
Lewis, W. J., M.B.E., elected Associate Member, 1200.
Liddell, Major-Gen. Sir W., K.C.M.G., Remarks on Sterilization of Water by Chlorine Gas, 1156.
Lidstone, A., elected Associate Member, 588.
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LIVERSIDGE, W., elected Associate Member, 588.

LIVINGSTONE, R., elected Associate Member, 590.

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LONGLEY, P. A. A., elected Graduate, 1201.

LONGMATE, H. W., elected Associate Member, 958.

LOWE, H., elected Associate Member, 588.

LOWE, J. W., elected Associate Member, 590.

LUBBOCK, I., elected Associate Member, 958.

LUMSDEN, T., elected Member, 587.

LYLE, D. L., elected Member, 587.

LYNAS, T. R. W., elected Associate Member, 958.

LYSAGHT'S WORKS, Scunthorpe, 815.

MCCALLUM, E. A., Memoir, 1318.

MCDERMOTT, T. H., elected Associate Member, 958.

MACDONALD, D. H., elected Graduate, 589.

MACGREGOR, J. C., elected Graduate, 959.

MACKECHNIE, J., elected Associate Member, 1200.

MACLEAN, A. D., elected Associate Member, 958.

MCQUAIGUE, F. E., Eng. Sub-Lieut., R.N.F., elected Associate Member, 588.

MAJOR, S. V., elected Associate Member, 590.

MALLETT, C., elected Associate Member, 1200.

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MARRECO, G. A. F., elected Associate Member, 958.

MARSDEN, J., elected Associate Member, 958.

MARSH, W. R., elected Associate Member, 590.

MARSHALL, A. W., Remarks on Sterilization of Water by Chlorine Gas, 1172.

MARSHALL, C. F. B., elected Member, 587.

MARSHALL, G. E. B., Capt. R.A.S.C., elected Associate Member, 588.

MARSHALLS' POWER STATION, Gainsborough, *Paper* by F. J. Cribb, 765.—Site on River Trent, 766.—Buildings; plant, 768.—Coal handling, 769.—Ashes; circulating water; cold-water service; boiler-feed make-up water, 770.—Old electric station.—New station, 772; results of tests, 773.

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MARSLAND, J., elected Member, 1199.

MARTIN, Q. Y., elected Associate Member, 590.

MARTINEAU, F. L., Remarks on Internal-Combustion Engine Development, 1272.

MARTLEW, S. G., Remarks on Some Lincolnshire Oil-Engines, 704.

MAUGHAN, J. D., elected Graduate, 959.

MAXIM, J. L., elected Associate, 589.

MAYNE, R. N., elected Member, 587.

MEASUREMENT OF HIGH DEGREES OF HARDNESS, *Paper* by J. Innes, 915.—Definition, 915.—Poisson's Ratio, and Ratio of Elastic Constants, 916.—Surface stresses, 921.—Measurement apparatus, 928.—Bibliography, 932.

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MELLOR, G. A., elected Associate Member, 1200.

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MIÉVILLE, A. L., D.S.O., M.C., Associate Member transferred to Member, 1202.

MILLER, J., Associate Member transferred to Member, 591.

MILLER, J. L., elected Associate Member, 958.

MILLER, W. E., elected Associate Member, 588.

MINES, R., elected Graduate, 589.

MITCHELL, W. C., elected Associate Member, 1200.

MIZEN, D. H., elected Graduate, 959.

MOLLE, N. F., elected Graduate, 959.

MONKHOUSE, E. W., seconded Motion for enlarging Council, 962.

MONTAGU, A. M. R., Capt., R.A.F., elected Associate Member, 588.

MONTGOMREY, J. E., appointed Assistant Secretary (Technical), 957.

MOORE, A. G., elected Graduate, 590.

MORLEY, T. B., Remarks on Coefficient of Discharge of Nozzles, 1026 :—on Internal-Combustion Engine Development, 1280, 1297.

MORRIS, C. C. B., Major, R.A.S.C., Remarks on Sterilization of Water by Chlorine Gas, 1195.

MORRIS, C. E., elected Associate Member, 958.

MORRIS, W. H., elected Graduate, 590.

MORSE, R. V., Major, D.S.O., elected Member, 587.

MORTIBOY, J. E., elected Member, 587.

MOSSCROP, G. W., elected Member, 587.

MOUL, F. D. elected Graduate, 591.
MOUNTAIN, S. R., elected Graduate, 1201.
MOWAT, M., C.B.E., Brig.-Gen., appointed Secretary, 956.—Thanks for appointment, 956.
MUNFORD, W. H., elected Graduate, 959.

NEWARK, Excursion at Lincoln Summer Meeting, 780.
NEWELL, P. B., elected Associate Member, 1200.
NEWTON, K., M.C., elected Associate Member, 1200.
NOBBS, W. W., Associate Member transferred to Member, 959.
NOËL, R. J. M. L., elected Graduate, 959.
NORTHFIELD, J. A., elected Associate Member, 1200.
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OGILVIE, G. M., elected Associate Member, 958.
OGLE, E. J., elected Associate Member, 588.
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OKELL, R., elected Member, 587.
OLLIER, T. H., elected Associate Member, 958.
O'MAHONY, C. C. S., Major, R.A.S.C., elected Associate Member, 1200.
ORCUTT, H. F. L., Remarks on the Human Factor in Industry, 1230.
ORGAN, C. A., Lt.-Col., D.S.O., R.A.S.C., elected Associate Member, 1200.
O'RIORDAN, G. F., elected Associate, 1201.
ORMOND, J. C., elected Associate Member, 588.
ORR, A. J., elected Associate Member, 590.
OSBORN, H. F., Associate Member transferred to Member, 591.
OSMOND, R. W., elected Associate Member, 588.
OWEN, A. D., Major, D.S.O., elected Member, 587.
OXLIN, H., elected Member, 587.

PADDON, W., elected Associate Member, 1200.
PAGE, A. C., elected Graduate, 1201.
PALMER, A. E., elected Associate Member, 1200.
PANE, H. A., elected Graduate, 1201.
PARISOT, E. O. W. La V., elected Graduate, 590.
PARKER, T. H. G., elected Associate Member, 588.
PARRY, E. M., elected Graduate, 1201.
PARSONS, A. F., elected Graduate, 1201.

PARTRIDGE, E. H. W., O.B.E., Major, R.A.S.C., elected Associate Member, 590.

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PATTERSON, A., Memoir, 1318.

PAUL, H. J., elected Associate Member, 588.

PAYNE, W. E., elected Associate Member, 590.

PENDRED, L. St. L., Remarks on Some Lincolnshire Oil-Engines, 704:—on Internal-Combustion Engine Development, 1275.

PENN, B. H., Major, R.A.O.C., elected Associate Member, 1200.

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PERRIN, M., elected Associate Member, 590.

PERROTT, A., elected Associate Member, 958.

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PETRIE, T., Remarks on Internal-Combustion Engine Development, 1288.

PETTER, E. W., Remarks on Internal-Combustion Engine Development, 1262.

PHILLIPS, H. C., elected Associate Member, 588.

PILGRIM, H. F., elected Graduate, 590.

PILLING, H., M.B.E., Remarks on the Uniflow Steam-Engine, 743.

PITT, P. S., seconded appointment of Brig.-Gen. M. Mowat as Secretary, 956.

PLETTS, J. St. V., elected Member, 1199.

POMEROY, C. C., elected Member, 587.

POTTS, J. G., elected Associate Member, 958.

POWELL, J. E., Remarks on the Human Factor in Industry, 1223.

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PRING, J., elected Member, 1199.

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angle, 905.—Tests on copper-alloys, 906; on pearlitic steels, 907; on Austenitic manganese steel; on Martensitic steels, 910.
PROEHL, W. F., elected Associate, 1201.
PRUNELL, T. L., elected Associate Member, 590.
PULLEN, J. F., elected Associate Member, 1200.
PURYER, P. L., elected Graduate, 1201.

RAMSAY, A., *Paper* on the Human Factor in Industry, 709.—Remarks thereon, 728, 1203, 1228.
RAMSDEN, H. W., elected Graduate, 590.
RANKIN, E. A., Memoir, 1319.
RANKIN, H. C., elected Associate Member, 1200.
RANSOME AND CO., Newark, 818.
RANSOME AND MARLES BEARING CO., Newark, 823.
REAVELL, K., elected Associate Member, 1200.
REAVELL, W., Remarks on the Human Factor in Industry, 719.
REEVES, E., elected Member, 1199.
REEVES, N., elected Graduate, 590.
REFUSE DESTRUCTOR, Lincoln, 787.
REID, H. W., elected Graduate, 590.
REID, L. G., elected Graduate, 1201.
REID, W. T., elected Associate Member, 589.
RENDLE, F. C., elected Associate Member, 589.
RESEARCH, Wire Ropes, 835.
REUSS, E., Remarks on Sterilization of Water by Chlorine Gas, 1181.
RICHARDSON, C. G. H., elected Associate Member, 1200.
RICHARDSON, J., Memoir, 1319.
RIDEAL, E. K., M.B.E., Remarks on Sterilization of Water by Chlorine Gas, 1158.
RIDEAL, S., Remarks on Sterilization of Water by Chlorine Gas, 1153.
RIDGWAY, W. J., elected Associate Member, 958.
RIDLEY, G. H., elected Graduate, 959.
RIDLINGTON, J., elected Member, 1200.
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Robb, W. G., elected Graduate, 590.
Robertson, Andrew, Associate Member transferred to Member, 591.
Robertson, Archibald, elected Associate Member, 958.
Robertson, G. W., Associate Member transferred to Member, 591.
Robertson, L. W. R., elected Graduate, 959.
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Rodger, J. B., Memoir, 1320.
Rogers, F., elected Member, 587.
Rollinson, E. W., elected Graduate, 590.
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Ross, A. J. C., C.B.E., elected Member, 957.
Rounthwaite, H. M., Remarks on the Human Factor in Industry, 1218.
Rowell, K., elected Graduate, 959.
Rusbridge, C. E., elected Graduate, 591.
Russell, A. B., elected Graduate, 590.
Russell, M., elected Member, 587.
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Ryan, J. W., elected Member, 1200.
Rycroft, J. E., Remarks on the Uniflow Steam-Engine, 760.

Sams, C. E. R., elected Associate Member, 1200.
Sankey, Capt. H. R., C.B., C.B.E., R.E., ret., Reply to Welcome at Lincoln Summer Meeting, 585.—Remarks on Roman Lincoln, 607 :—on Recent Excavator Practice, 631, 635 :—on Road Transport by Steam-Vehicles, 661 :—on Some Lincolnshire Oil-Engines, 698, 706 :—on the Human Factor in Industry, 716, 721 :—on the Uniflow Steam-Engine, 743 :—on Marshalls' Power Station, Gainsborough, 774 :—at Institution Dinner, Lincoln, 778, 779 : —on retirement of E. Worthington as Secretary, 955.—Moved appointment of Brig.-Gen. M. Mowat as Secretary, 956.—Remarks on appointment of H. T. Chapman and J. E. Montgomrey as Assistant Secretaries

957 :—on appointment of Lt.-Col. A. E. Davidson as Member of Council, 957 :—on alterations of Articles of Association, 961, 962, 967, 973.—Presidential Address, 1039.—Acknowledged Vote of Thanks, 1074.—Remarks on Sterilization of Water by Chlorine Gas, 1153 :—on the Human Factor in Industry, 1207 :—on Internal-Combustion Engine Development, 1261, 1275.

Savage, G. H., Capt., R.A.S.C., Remarks on Road Transport by Steam-Vehicles, 669 :—on the Human Factor in Industry, 724.

Saville, R. T., elected Graduate, 959.

Sawyer, W. H., elected Graduate, 590.

Scoble, W. A., *Report* to the Wire Ropes Research Committee, 835.

Scott, F. D., Major, R.A.O.C., elected Associate Member, 589.

Scott, H., elected Associate Member, 958.

Scott, J., Memoir, 1320.

Scott, W. H., elected Associate Member, 589.

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Seddon, H., elected Member, 1200.

Segrott, R. F., elected Associate Member, 1200.

Sellman, T. D., elected Graduate, 1201.

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Shaw, W. M., Associate Member transferred to Member, 960.

Silk, P. R. G., elected Graduate, 590.

Sillcox, L. K., elected Associate Member, 958.

Sims, J. W., elected Associate Member, 590.

Skinner, A. J., M.C., elected Associate Member, 1201.

Skinner, T. V., elected Graduate, 590.

Slade, T., elected Graduate, 590.

Slattery, L., elected Graduate, 1201.

Slaughter, E. W., Major, M.B.E., R.A.O.C., elected Associate Member, 1201.

Smith, L. W., Remarks on the Human Factor in Industry, 722.

Smith, S. B., elected Associate Member, 958.

Smith, W. G., elected Member, 587.

Soper, S. W., elected Graduate, 1201.

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Sparks, A. C., M.C., elected Associate Member, 589.

Speir, R. F., elected Associate Member, 958.

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Sproson, H., elected Associate Member, 590.

Spurgeon, C. E., elected Member, 587.

Spyer, A., elected Member, 1200.

Stacey, H. R., elected Graduate, 590.
Stamp, S. H., elected Associate Member, 1201.
Stanton, A. L., elected Associate Member, 589.
Stark, W. H. C., elected Graduate, 1201.
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Stickings, Capt. R. W. E., O.B.E., Remarks on Sterilization of Water by Chlorine Gas, 1169.
Stilwell, R. P., elected Graduate, 590.
Stoddart, R., elected Associate Member, 958.
Stoney, G. G., Remarks on Internal-Combustion Engine Development, 1303.
Stowers, A., elected Graduate, 1201.
Stoyle, C. C., elected Graduate, 1201.
Strange, H. W. J., Major, elected Associate Member, 958.

STRICKLAND, F. W., elected Member, 587.
STURGEON, R. A., elected Associate Member, 589.
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SUMPNER, P. J., elected Graduate, 1201.
SUTHERLAND, S. B., elected Associate Member, 958.
SUTHERLAND, S. N., elected Associate Member, 590.
SWANN, A. H., elected Graduate, 1201.
SWIFT, A. M., elected Member, 587.
SWINGLER, G. H., Associate Member transferred to Member, 960.
SYMPSON, Lt.-Col. E. M., M.A., M.D., *Lecture* on Roman Lincoln, 595.

TAHOURDIN, H. D'A., elected Associate Member, 958.
TASSELL, A. J., Memoir, 1321.
TAYLOR, C. H., elected Associate Member, 589.
TAYLOR, G., elected Graduate, 1202.
TAYLOR, G. E., elected Associate Member, 589.
TAYLOR, R. E., Remarks on Sterilization of Water by Chlorine Gas, 1197.
TAYLOR, W. A. T., M.B.E., Associate Member transferred to Member, 1202.
TAYLOR, W. H., Memoir, 1321.
TETLEY, M. H., elected Member, 587.
THACKERAY, E. R., Capt., R.A.O.C., elected Associate Member, 958.
THERMODYNAMICAL CYCLES OF INTERNAL-COMBUSTION ENGINES, 1235. *See* Internal-Combustion Engine Development.
THOM, M., Capt., R.A.S.C., elected Associate Member, 958.
THOMAS, W. N., *Paper* on Helical Springs, 869.
THOMAS HAWKSLEY LECTURE, 1920, by Sir R. T. Glazebrook, K.C.B., 1075. *See* Limit Gauging.
THOMPSON, G. W., Remarks on alteration of Articles of Association, 967.
THOMPSON, R. W., elected Associate Member, 589.
THOMPSON, V. S., elected Graduate, 1202.
THOMPSON, W., elected Associate Member, 1201.
THOMSON, R. R., elected Associate Member, 1201.
THORNHILL, G. C., elected Associate Member, 589.
THORPE, W. B., Associate Member transferred to Member, 591.
THURSTON, A. P., Remarks on the Human Factor in Industry, 1225.
TIMMIS, C., elected Associate Member, 958.
TITT, A. J. B., elected Member, 587.
TOMLIN, W., elected Graduate, 1202.
TOMLINSON, T. A., elected Member, 587.
TOOBY, C. F., elected Associate Member, 590.
TOOKEY, W. A., Remarks on Some Lincolnshire Oil-Engines, 701:—on Internal-Combustion Engine Development, 1273.

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TRAVERS, L. A., elected Associate Member, 958.
TREEBY, W. V., elected Associate Member, 590.
TURNER, E. H., elected Graduate, 1202.
TURNER, L. A., elected Graduate, 1202.
TURNER, W., elected Associate, 1201.
TURNER-SMITH, W., elected Associate Member, 958.
TWEEDLIE, J. R. G., elected Member, 1200.
TWEEDY, R. A. M., elected Graduate, 959.
TWELLS, J., Associate Member transferred to Member, 960.
TWINBERROW, R. W. K., Eng. Lt., R.N., elected Graduate, 1202.

UNIFLOW STEAM-ENGINE, *Paper* by F. B. Perry, 731.—History, 731.—Principle and special features, 733.—Advantages: economy, 734; flexibility; speed-control, 736; up-keep; floor space and foundations, 738.—Details of design, 738.
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URQUHART, R. N., elected Associate Member, 589.
URWIN, C. R., elected Graduate, 1202.

VALON, W. A. McI., Associate Member transferred to Member, 1202.
VARIAN, E. N., elected Graduate, 591.
VENNING, H. C. W., elected Associate Member, 958.
VOSE, H. J., elected Member, 587.
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WADE, F. R., Remarks on alteration of Articles of Association, 969.
WAGHORNE, H., elected Graduate, 1202.
WALKE, C. N. E., Memoir, 1321.
WALKER, P. S., elected Graduate, 590.
WALKER, W. J., *Paper* on Thermodynamical Cycles in relation to the design and future development of Internal-Combustion Engines, 1235.—Remarks thereon, 1258, 1277, 1284, 1293, 1304.
WALSH, E. L., elected Graduate, 1202.
WALSH, H. T., elected Graduate, 1202.
WALSH, J. N., elected Member, 587.
WARREN, A. G., elected Associate, 589.
WATER STERILIZATION BY CHLORINE GAS, 1127. *See* Sterilization of Water by Chlorine Gas.

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WATSON, C. C., elected Associate Member, 1201.
WATT, E., elected Graduate, 590.
WEISS, R. G. A., elected Graduate, 590.
WELCH, T. B., elected Graduate, 590.
WELCH, W., elected Associate Member, 591.
WELLINGHAM, H. J., M.C., elected Associate Member, 589.
WESTWOOD, R. E., Remarks on Recent Excavator Practice, 632.
WHITE, E. D., elected Associate Member, 1201.
WHITFIELD, W., Jun., elected Associate Member, 589.
WHITTAKER, H., elected Associate Member, 589.
WHITTAKER, T. A., elected Member, 1200.
WHITTAKER, W. J., elected Associate Member, 959.
WILLIAMS, C., Associate Member transferred to Member, 1202.
WILLIAMS, J., elected Associate Member, 959.
WILLIAMS, W. T., elected Member, 957.
WILSON, A. J., elected Graduate, 959.
WILSON, C. V., Lieut., R.A.S.C., elected Associate Member, 959.
WILSON, F. B., elected Associate Member, 589.
WILSON, G. H., elected Associate Member, 591.
WINDELER, G. E., Remarks on Internal-Combustion Engine Development, 1291.
WIRE ROPES RESEARCH, *Report* by W. A. Scoble, 835.—Introduction, 835. -Wire: composition, strength, 836; diameter, 839; coating, 839.—Rope: construction; lay, 840; Lang's Lay; special ropes, 841; cores; corrosion, 843; lubrication, 844; modulus of elasticity, 845.—Pulleys and drums: diameter, 846; condition, 849; slip, 850.—Repeated bending, 850: theory, 850; reverse turns; angle of bending, 855; test results, 857.—Conclusion, 861. —Bibliography, 864.—List of Members of the Committee, 868.
WITCHELL, E. F. D., elected Member, 1200.
WOLLASTON, T. R., Remarks on Sterilization of Water by Chlorine Gas, 1182.
WOOD, J. H. V., elected Graduate, 959.
WOOD, T. H., elected Associate Member, 589.
WOOD, W. B., elected Associate Member, 959.
WOODFIELD, C. H., Remarks on alteration of Articles of Association, 967.
WOODROW, R. H., elected Associate Member, 591.
WOODS, E. E., Associate Member transferred to Member, 960.
WORTHINGTON, E., Retirement from Secretaryship, 955.
WORTHINGTON-SIMPSON, Newark, 825.
WRAITH, H. O., Major, elected Member, 1200.

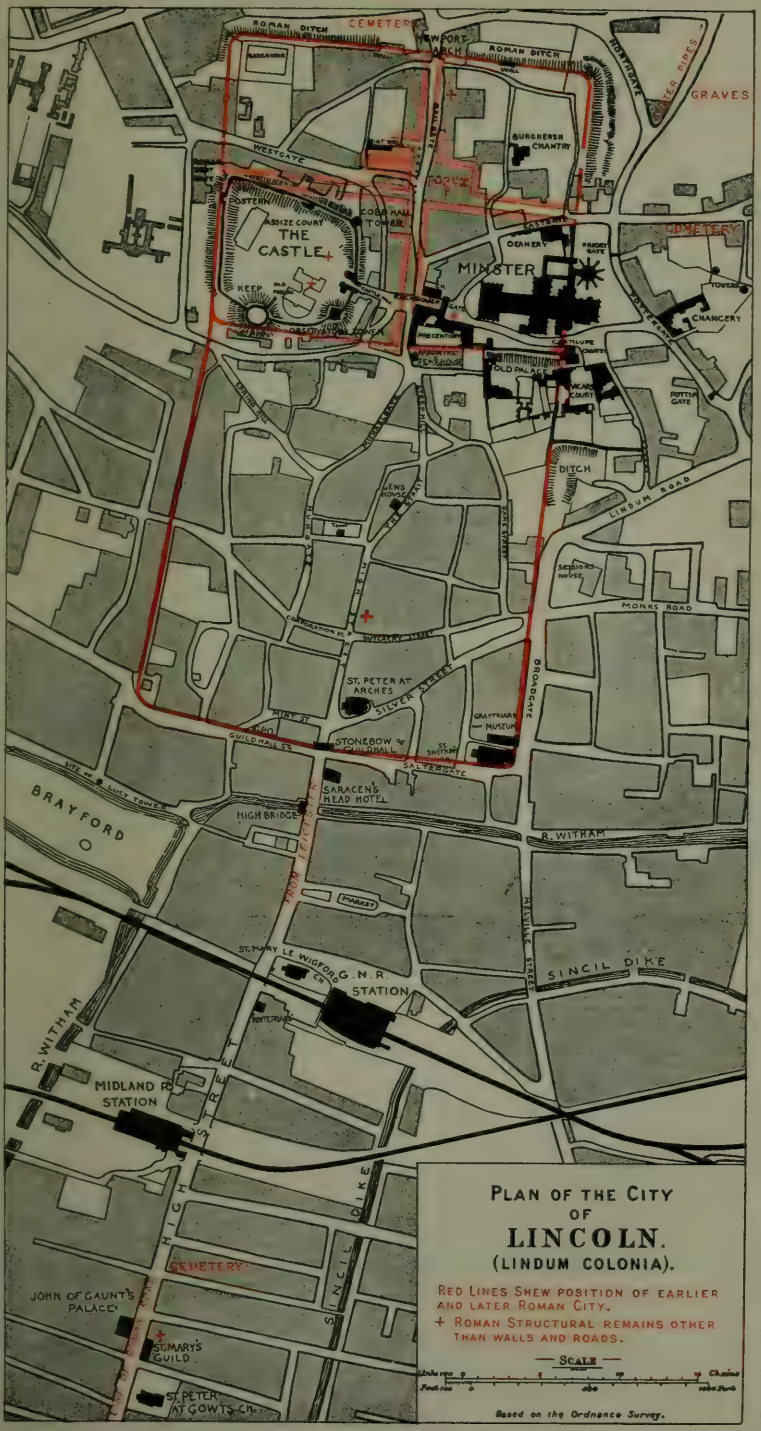
Yarwood, A., elected Member, 1200.
Yates, A. E., Associate Member transferred to Member, 591.
Yates, H., elected Associate Member, 589.
Younger, W. G., elected Member, 587.

Zackariasen, N., elected Associate Member, 959.

ROMAN LINCOLN.

Plate 1.

Lecture by Lieut.-Colonel E. Mansel Sympson, M.A., M.D.



PLAN OF THE CITY
OF
LINCOLN.
(LINDUM COLONIA).

RED LINES SHEW POSITION OF EARLIER AND LATER ROMAN CITY.
+ ROMAN STRUCTURAL REMAINS OTHER THAN WALLS AND ROADS.

SCALE

Based on the Ordnance Survey.

By kind permission of the Royal Archæological Institute.

Mechanical Engineers 1920.

Fig. 2. *Crane-Navvy excavating Ironstone and loading it direct into wagon.*

Fig. 4. *Crane-Navvy with long jib to excavate a face 40 ft. in height.*

Fig. 5. *Combined Crane-Navvy and Grab (showing Grab in use).*

Fig. 6. *Crane-Navvy with extra long Bucket-Arm and Jib. Bucket discharging 60 ft. from centre of machine.*

Fig. 7. *Crane-Navvy working in conjunction with a Transporter.*

Fig. 8. *Combined Excavator and Transporter, removing cover from Ironstone.*

Fig. 9. *Endless-Bucket Excavator combined with Belt Conveyor.*

Fig. 10. *Small Crane-Navvy excavating clay for brickmaking.*

Fig. 12. *Coke Loader at work on a coke bench.*

Fig. 13. *Large Crane-Navvy, 120 tons in weight. (Side sheets of housing removed to show engines and gearing.)*

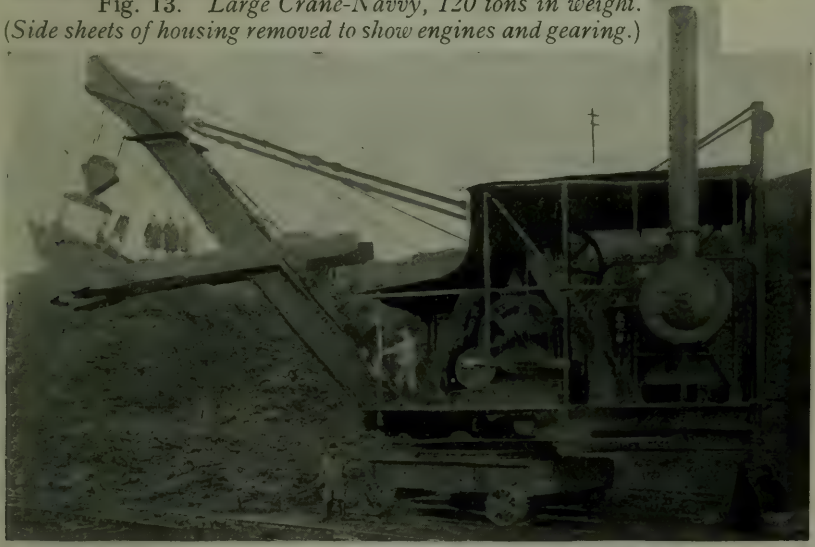
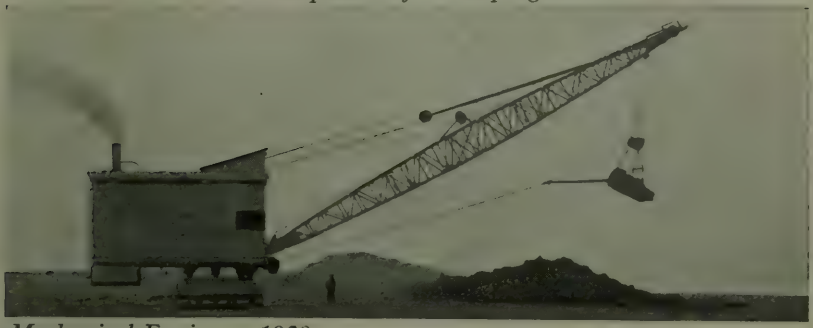


Fig. 15. *Dragline Excavator at work, with full bucket, in position for dumping.*



Over-types.

Fig. 10. *"Clayton," 5-ton.*

Fig. 11. *"Foden," 5-ton.*

Fig. 12. *"Garrett," 5-ton.*

Over-type.
Fig. 13. *"Mann," 5-ton.*

Under-type.
Fig. 14. *"Sentinel," 6-ton.*

High-Speed Engine Type.
Fig. 15. *"Clarkson," 5-ton.*

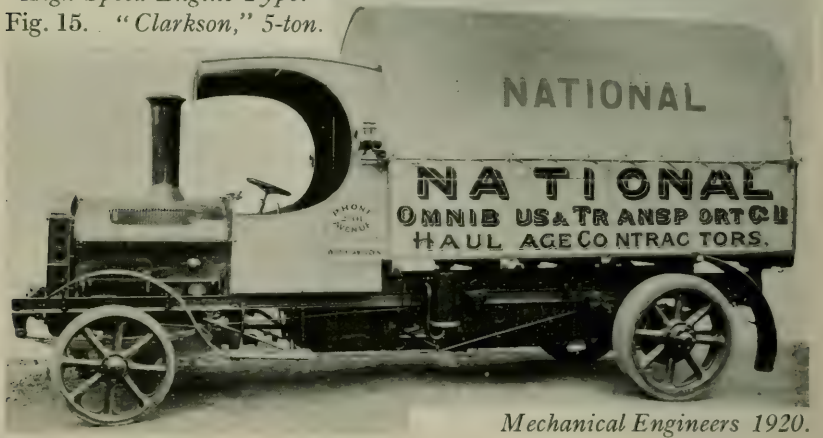


Fig. 10. *High Compression Oil-Engine.*
Ruston, Proctor and Co.
1915 Type. (*Starting from cold.*)

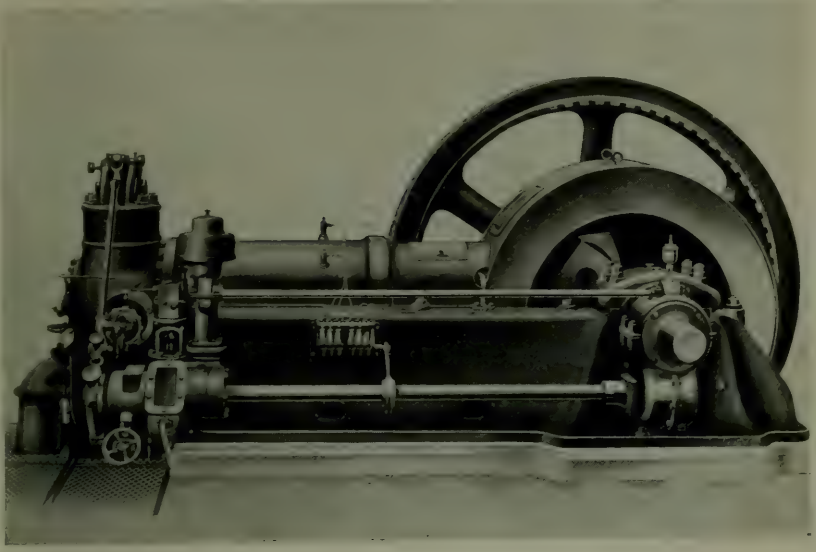


Fig. 17. *Twin High Compression Oil-Engine.*
Ruston and Hornsby.
1915 Type. (*Starting from cold.*)
(*See The President's Remarks.*)

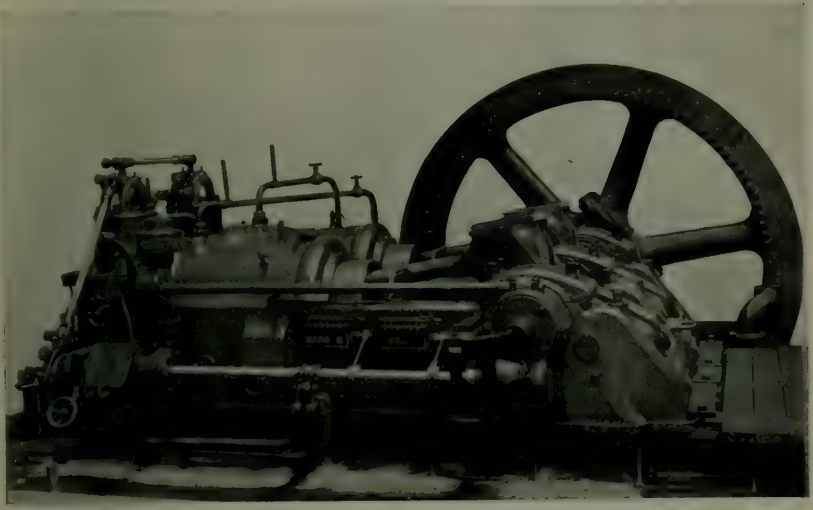


Fig. 6. *1,100 I.H.P. Uniflow Engine with Generator, see Fig. 7.*

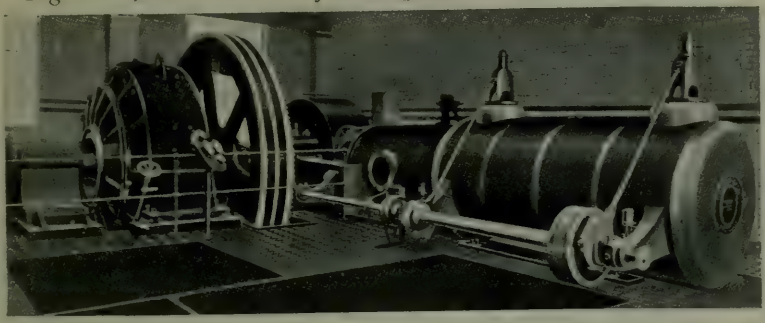


Fig. 8. *Bed for Uniflow Engine.*

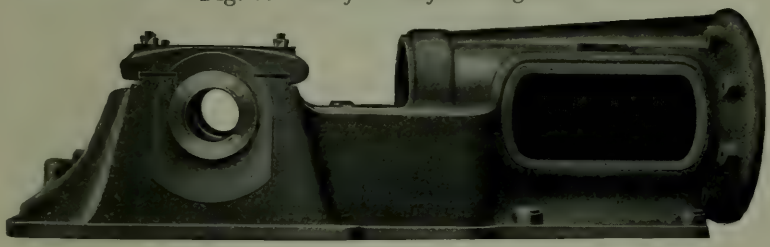


Fig. 11. *Cylinder and Gear for Slow-Speed Engine, Fig. 10.*

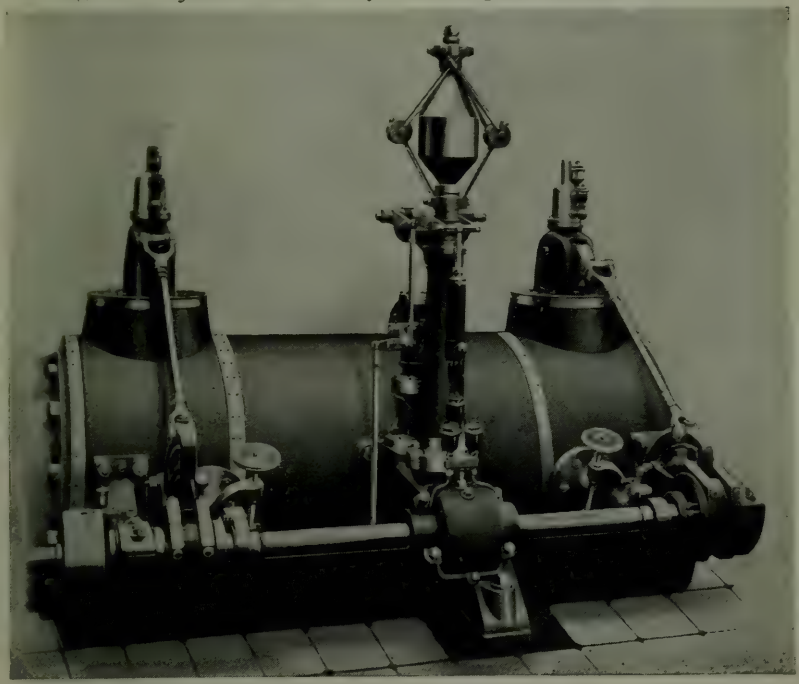


Fig. 1. *Site from the River Trent (as purchased).*

Fig. 3. *Two 1,500 kilowatt Turbo-Generators (Ljungstrom).*

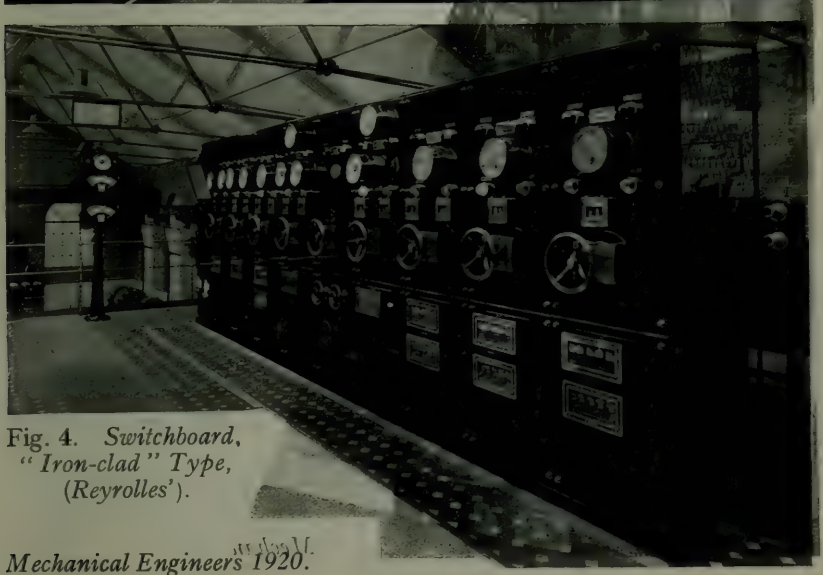
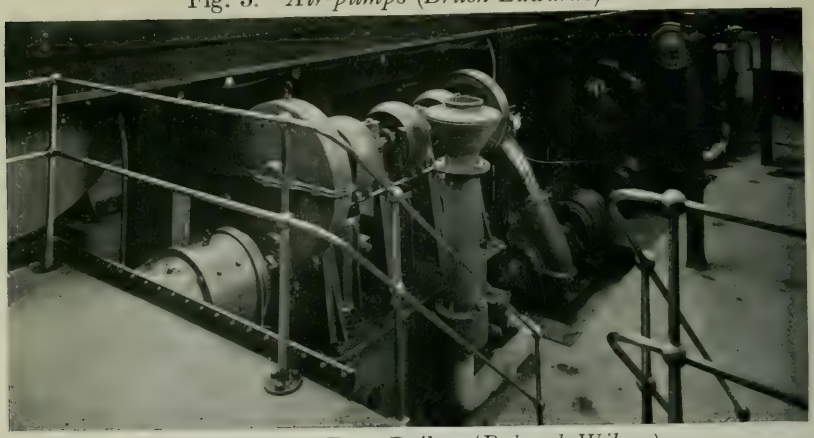


Fig. 4. *Switchboard, "Iron-clad" Type, (Reyrolles').*

Plate 10. **MARSHALLS' POWER STATION, GAINSBOROUGH.**

Fig. 5. *Air-pumps* (*Brush-Edwards*).



Figs. 6 and 7. *Four Boilers* (*Babcock-Wilcox*).

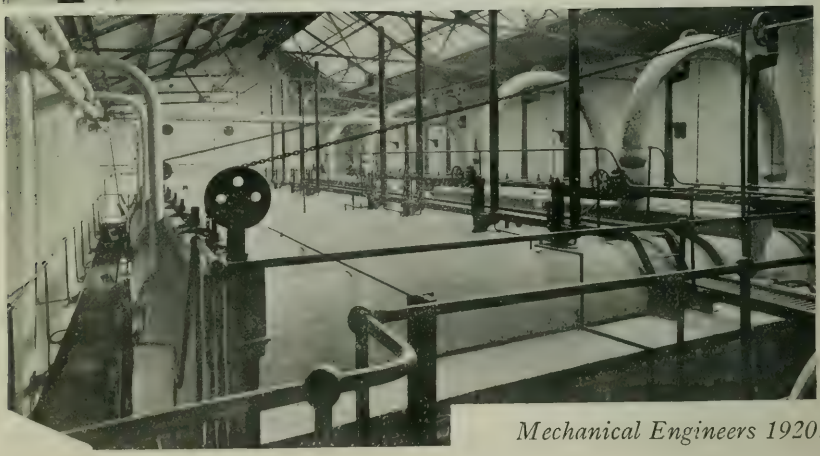


Fig. 8. *20-ton Evaporator (Caird and Rayner).*

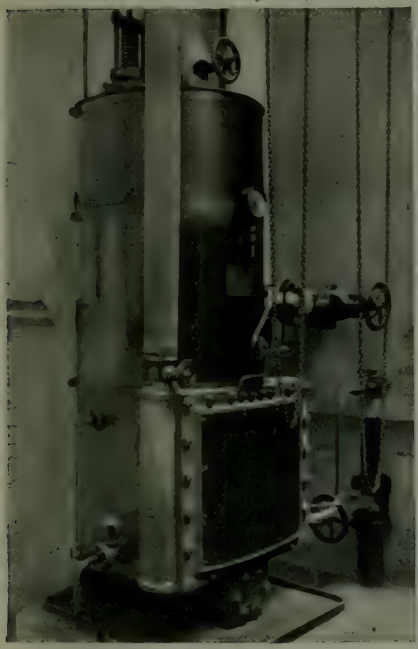


Fig. 9. *Single-Turbo (Weir) and 6-series Motor-driven (Pulsometer) Centrifugal Pumps.*

Fig. 10. *General View of Power Station from River Trent.*

Fig. 5. *Jig with Crossed Prisms in place.*

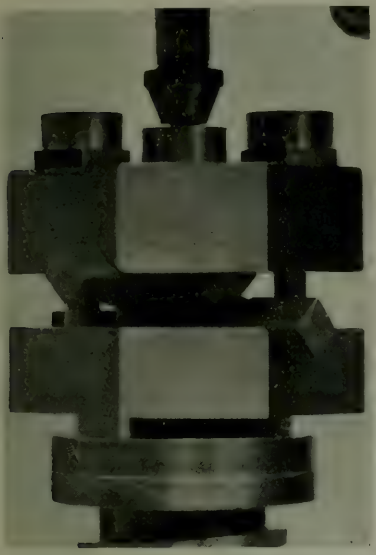
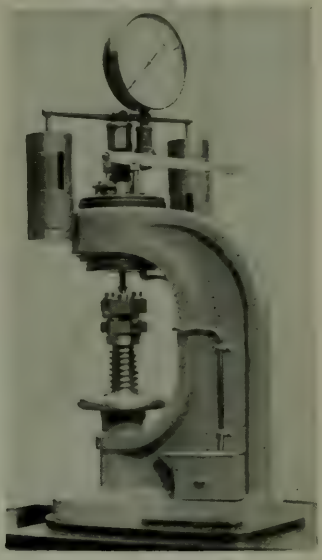


Fig. 6. *3,000 Kg. Brinell Testing-Machine with Jig for Crossed-prism test.*



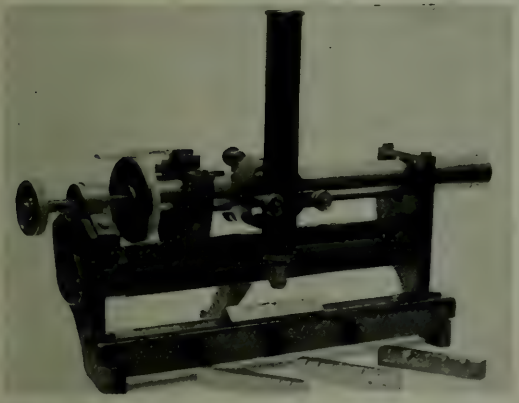


Fig. 7. *Measuring Microscope used for taking widths of indentations; with Mild-steel Prism in place.*

Shows other Prisms, viz., Hard-drawn Copper, Austenitic Steel, Martensitic Steel.

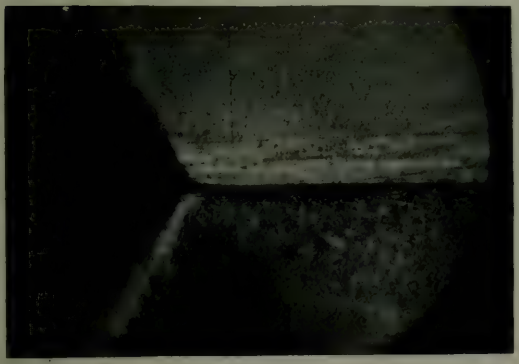


Fig. 8. *Corner of Indentation as viewed with high magnification through the Measuring Microscope, with graticule.*

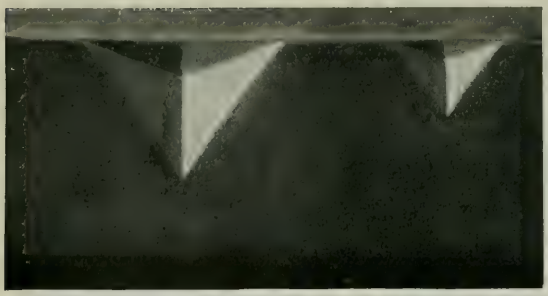


Fig. 10.
Widespread Indentation in Annealed Copper.
$\times 2\frac{1}{4}$.

Fig. 11.
Localized Indentation in Hard-drawn Copper.
$\times 2\frac{1}{4}$.

Fig. 13.
Side view of Indentation in 60° *special prism. Hard-drawn Copper.*

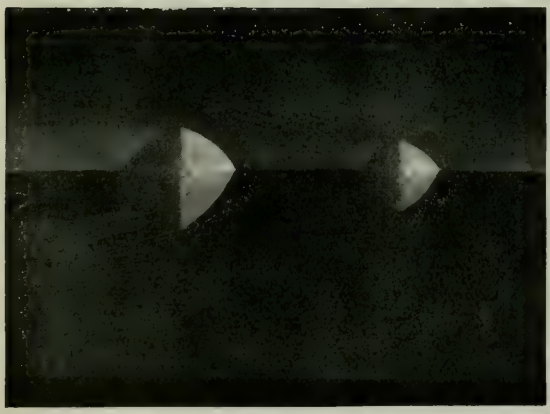


Fig. 14.
Plan View of Shallow Indentation in 120° *special prism. Hard-drawn Copper.*

Fig. 1.
Section of Standardizing Box (Amsler).

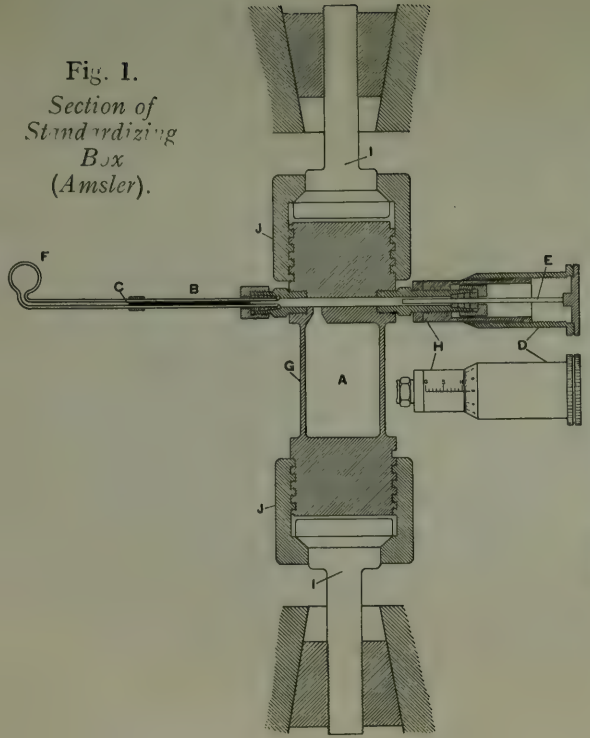


Fig. 2. *30-ton Standardizing Box in Tensile Testing Machine.*

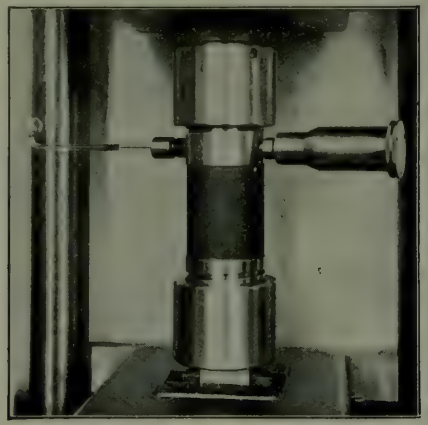


Fig. 3.
Double purpose Standardizing Box arranged for Compression Test.

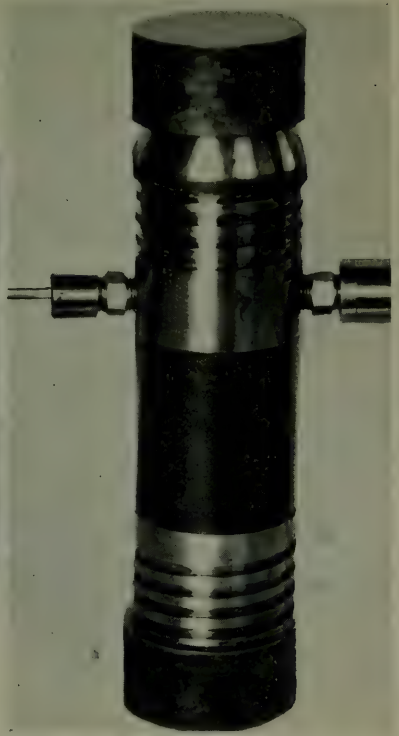


Fig. 5. *5,000 Kg. Screw-Press with Elastic Column Dynamometer for Hardness Tests.*

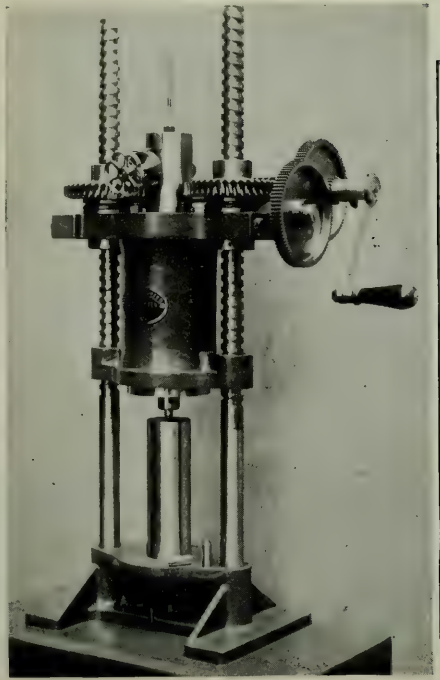


Fig. 7.
Depth Indicator (Amsler) for Hardness Tests.

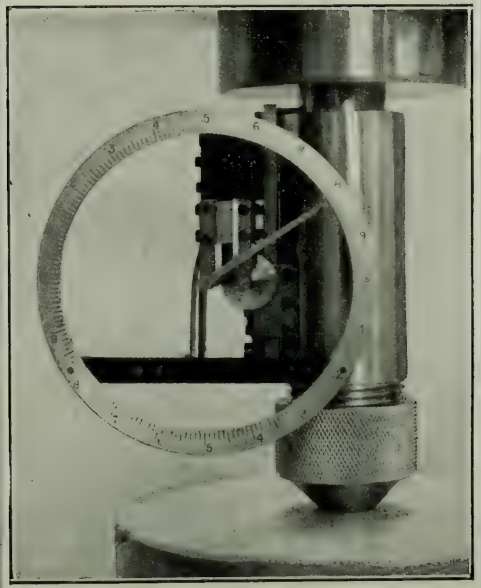


Fig. 12. *5,000 Kg. Hydraulic Press with Pendulum Dynamometer for Hardness Tests.*

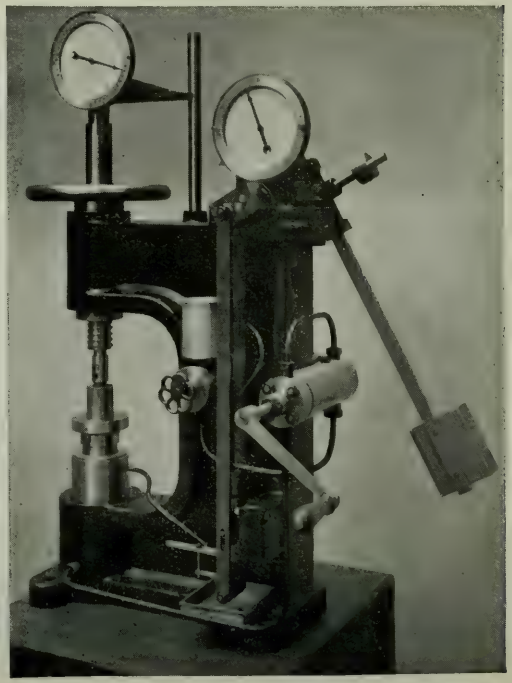


Fig. 12. *Millionth Measuring Machine (Brookes').*

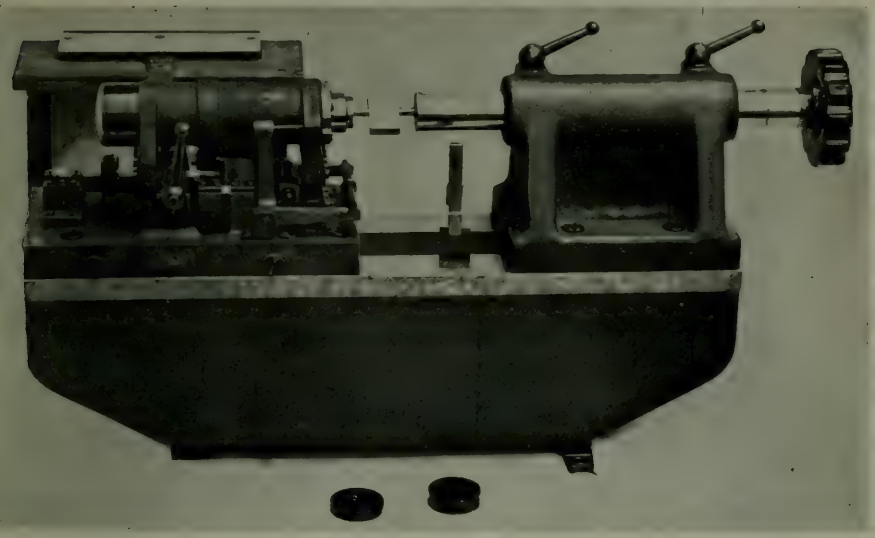
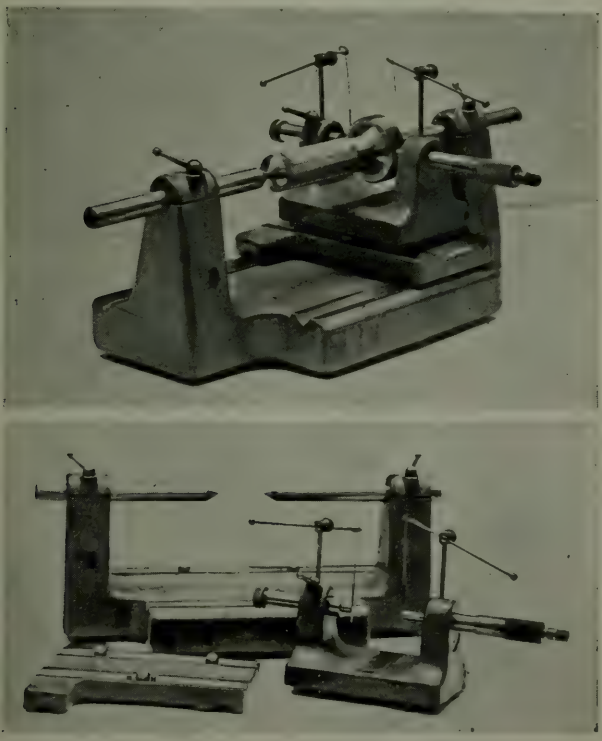


Fig. 15. *Floating Micrometer Screw Diameter Measuring Machine.*



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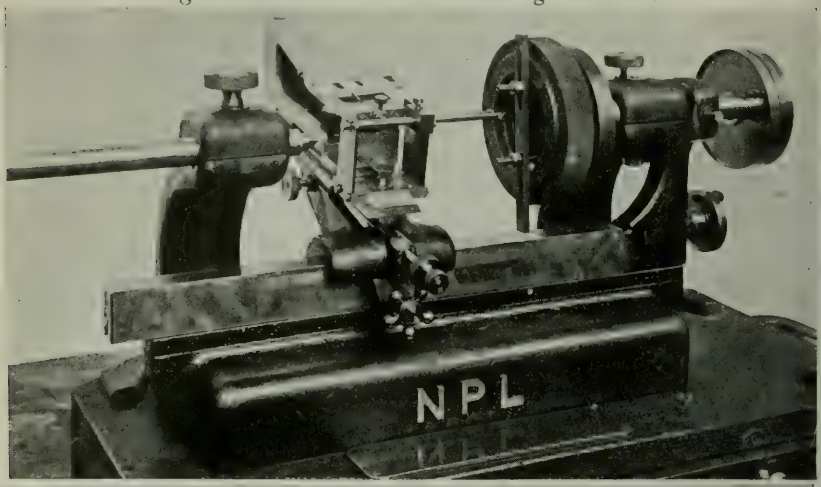
Figs. 17 and 18. *Pitch Measuring Machines.*



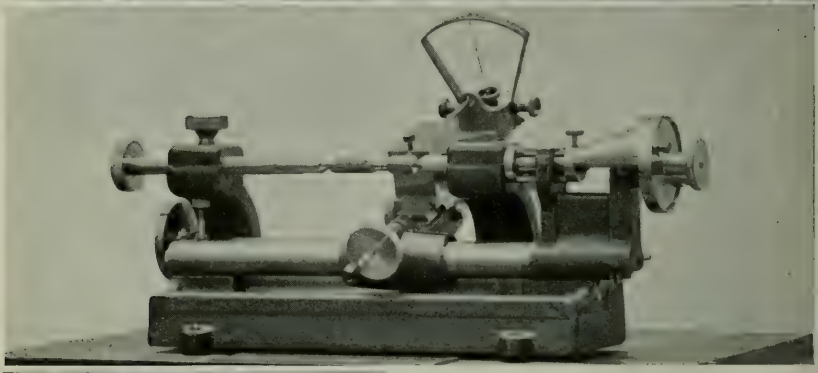


Fig. 20.
Horizontal Projector.

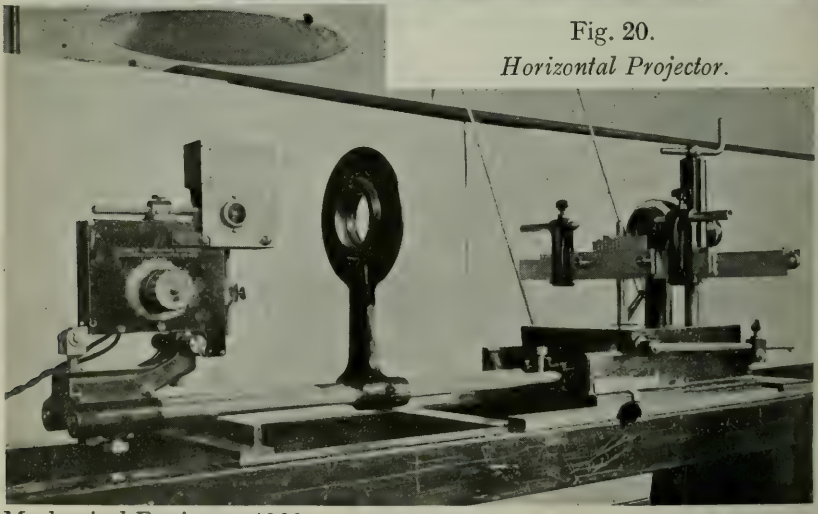
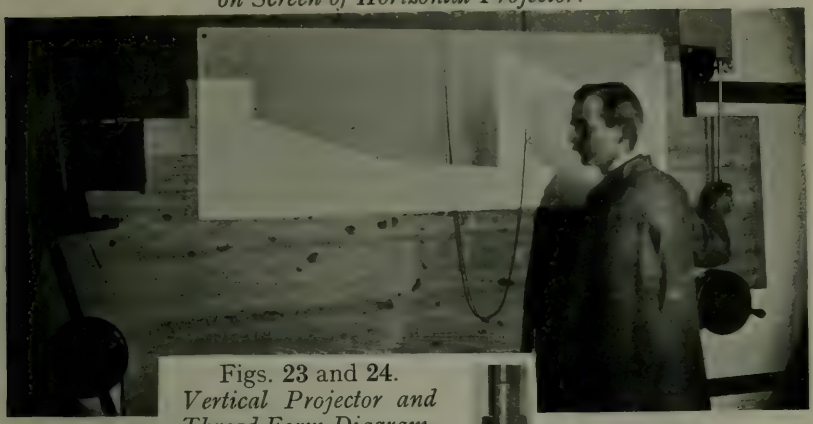


Fig. 21. *Observer comparing shadow of Form Gauge against the Diagram on Screen of Horizontal Projector.*



Figs. 23 and 24.
Vertical Projector and Thread Form Diagram.

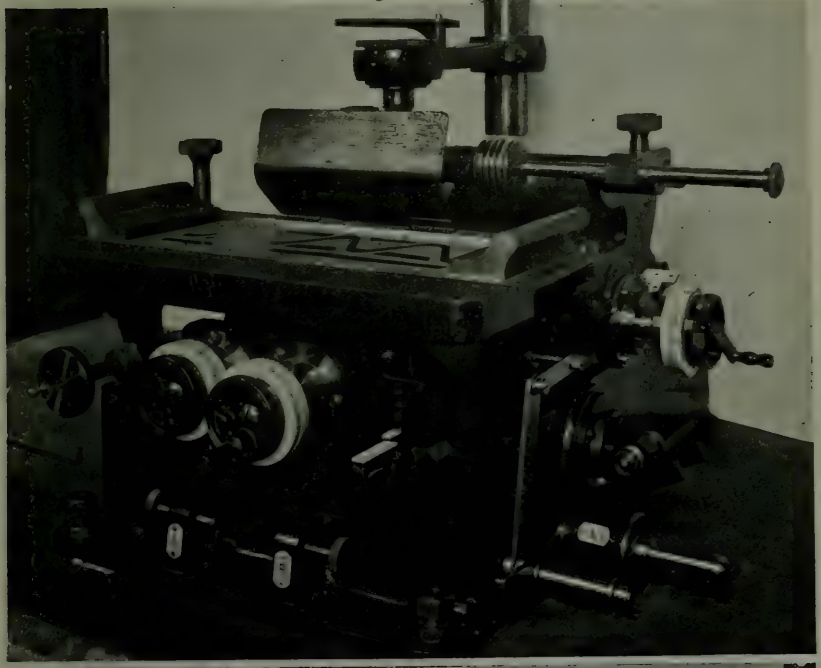


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Fig. 26. *Projection Comparator (Wilson).*

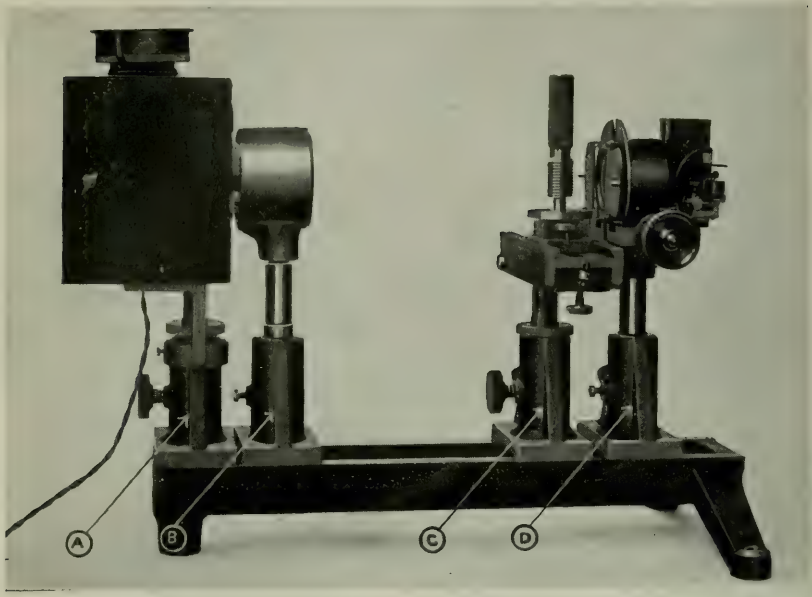

Fig. 27. *Front view of Projection System with Transposing Prisms swung aside.*

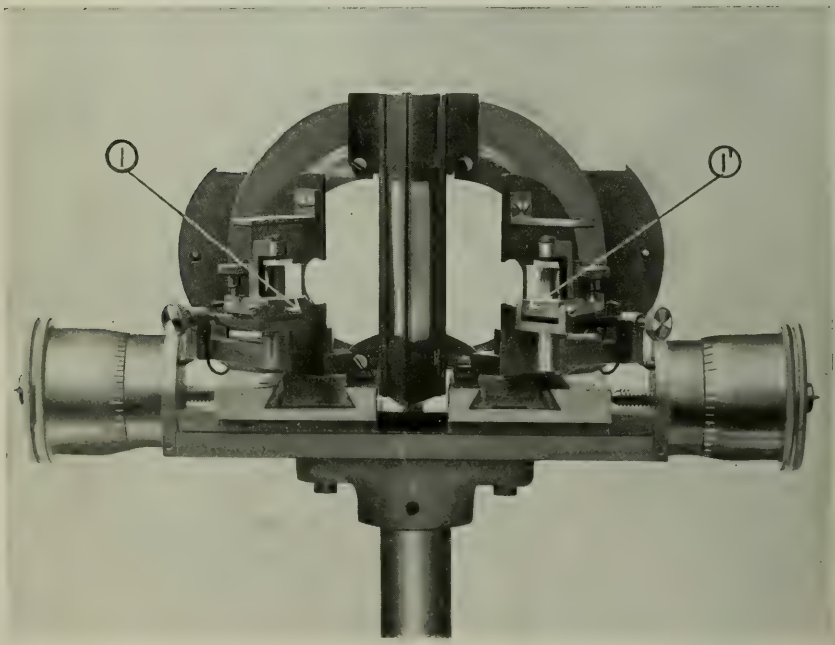

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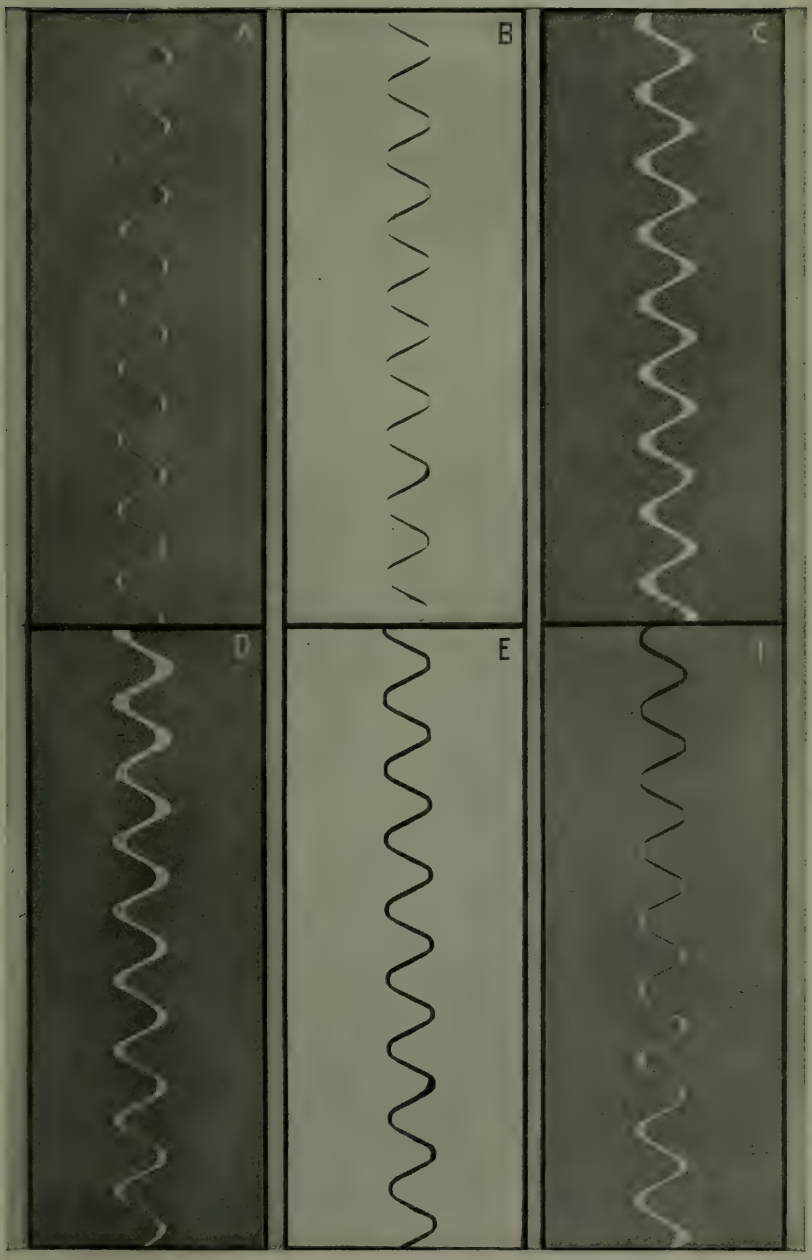
Fig. 28. *Some Typical Screw-Thread Projections.*



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Chlorinator
(Wallace-Tiernan).

Fig. 2. *Direct-Feed Manual Control.*

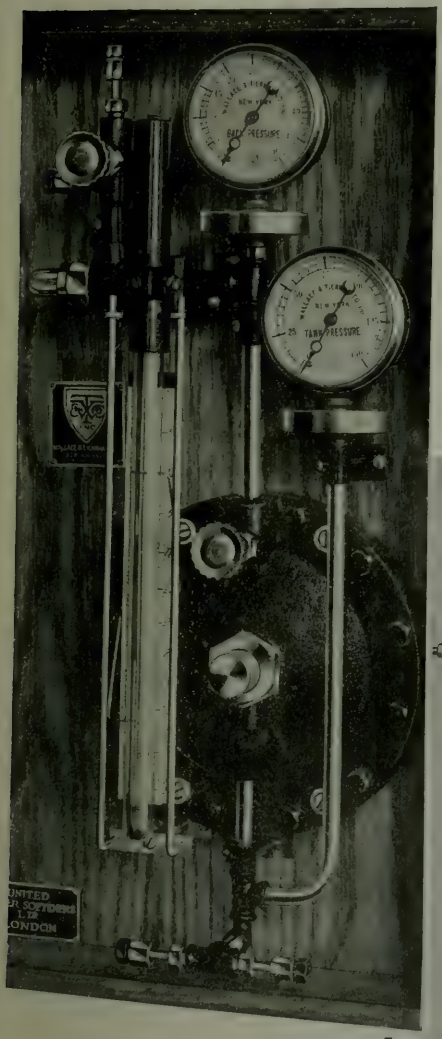
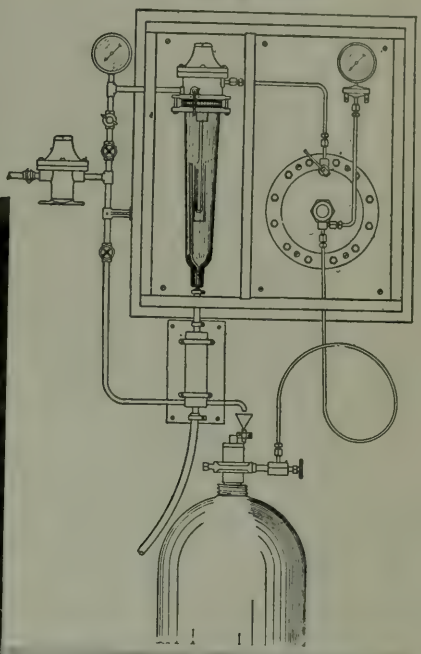


Fig. 7. *Solution-Feed Pulsating Meter.*



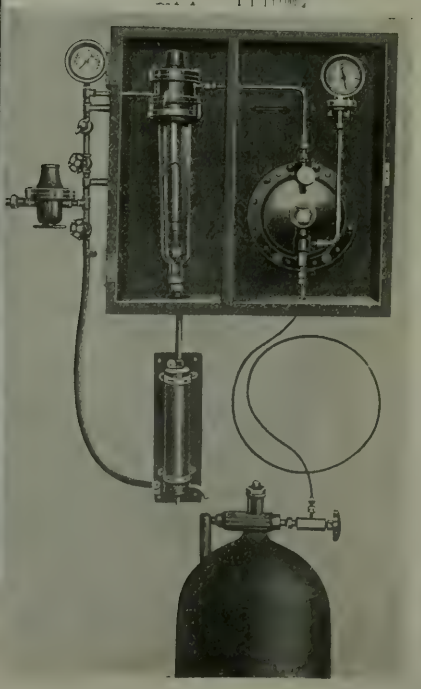


Fig. 10. *Original Bleaching Powder Type, 125 gallons per hour.*

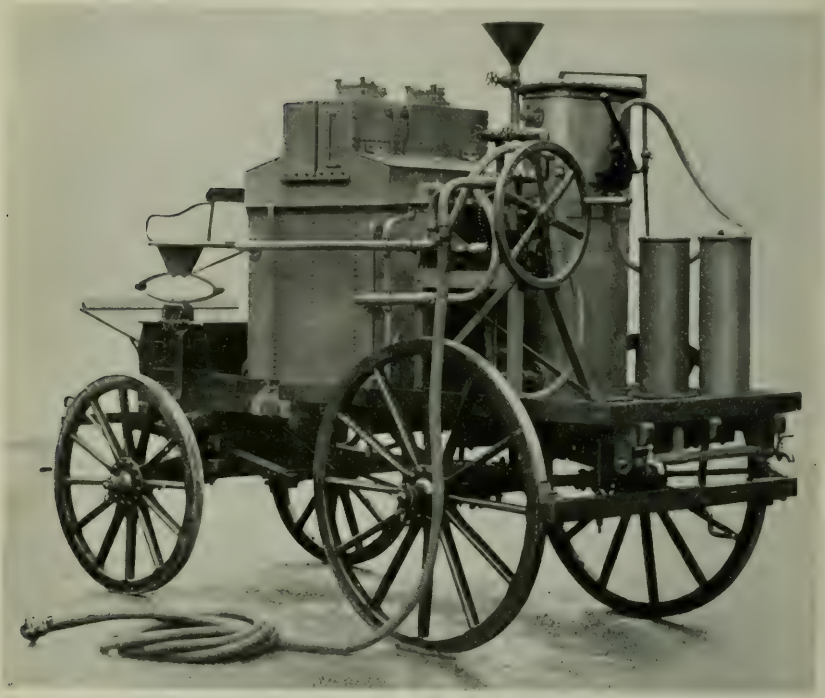
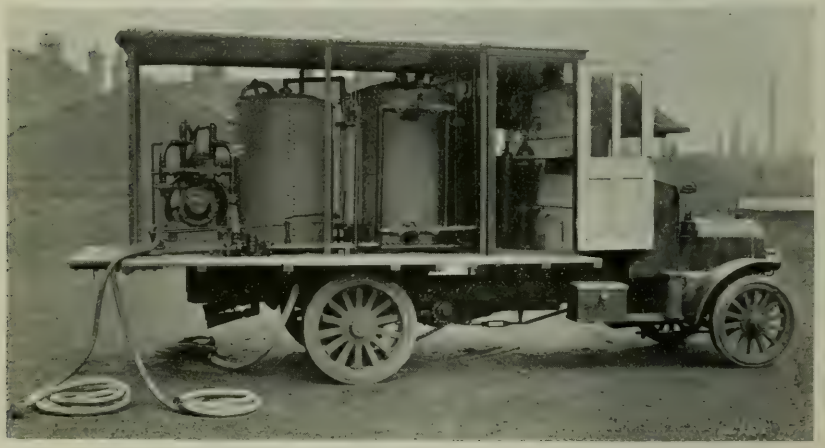


Fig. 11. *Original Machine actually constructed by the Author.*



Figs. 12 & 13.
Army Type.

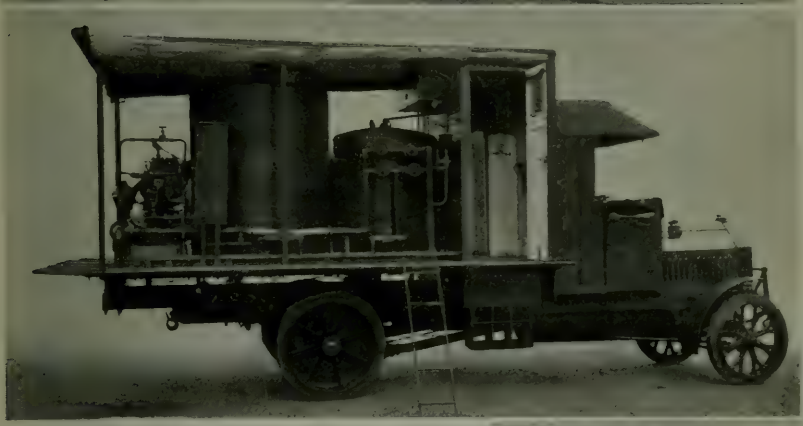


Fig. 14. *Indian Type.*

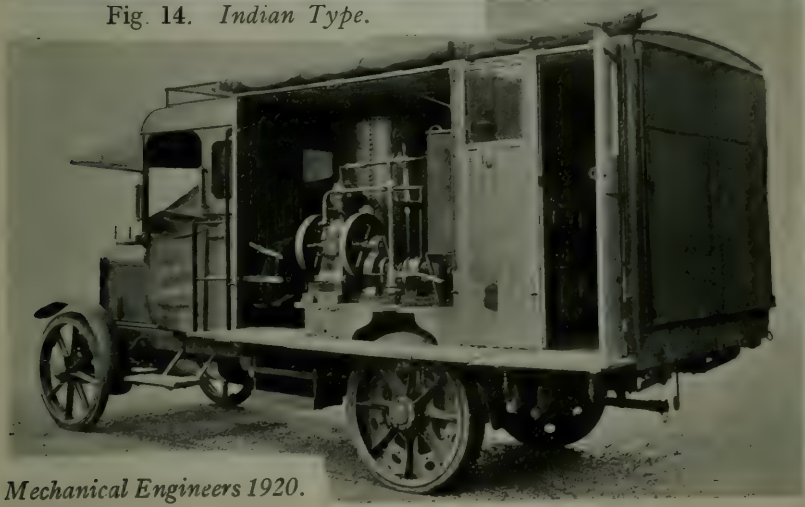


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Plate 24. **STERILIZATION OF WATER BY CHLORINE GAS.**

(Mr. V. Hjort's remarks.)

Fig. 19. *First Hand Pumping Equipment, temporarily mounted.*

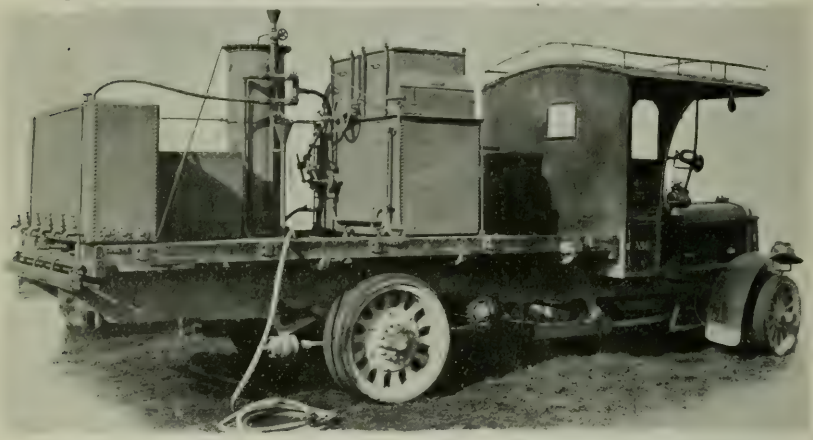


Fig. 20. *Plant for sterilizing or for taking poison out of water.*

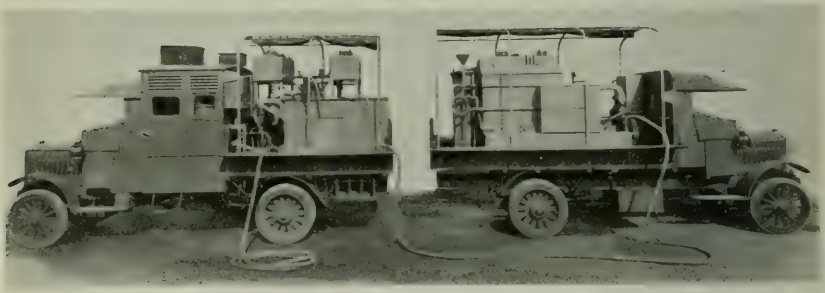
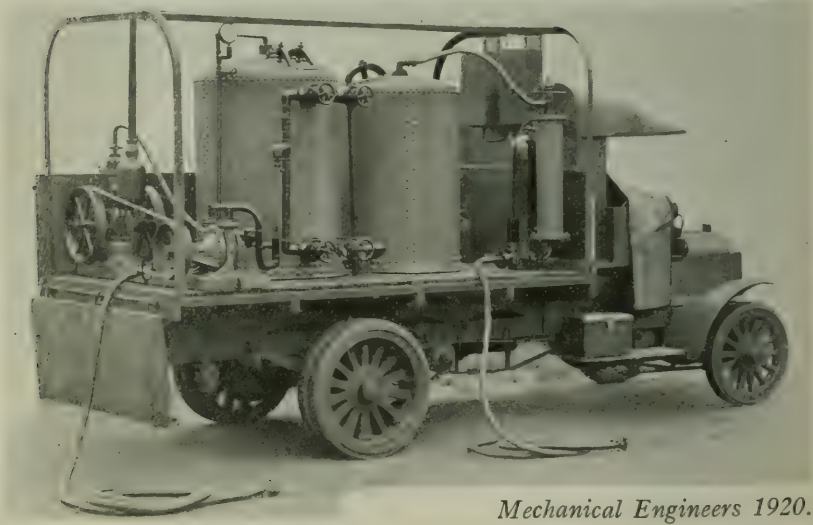


Fig. 21. *First Chlorine Gas apparatus, temporarily mounted.*



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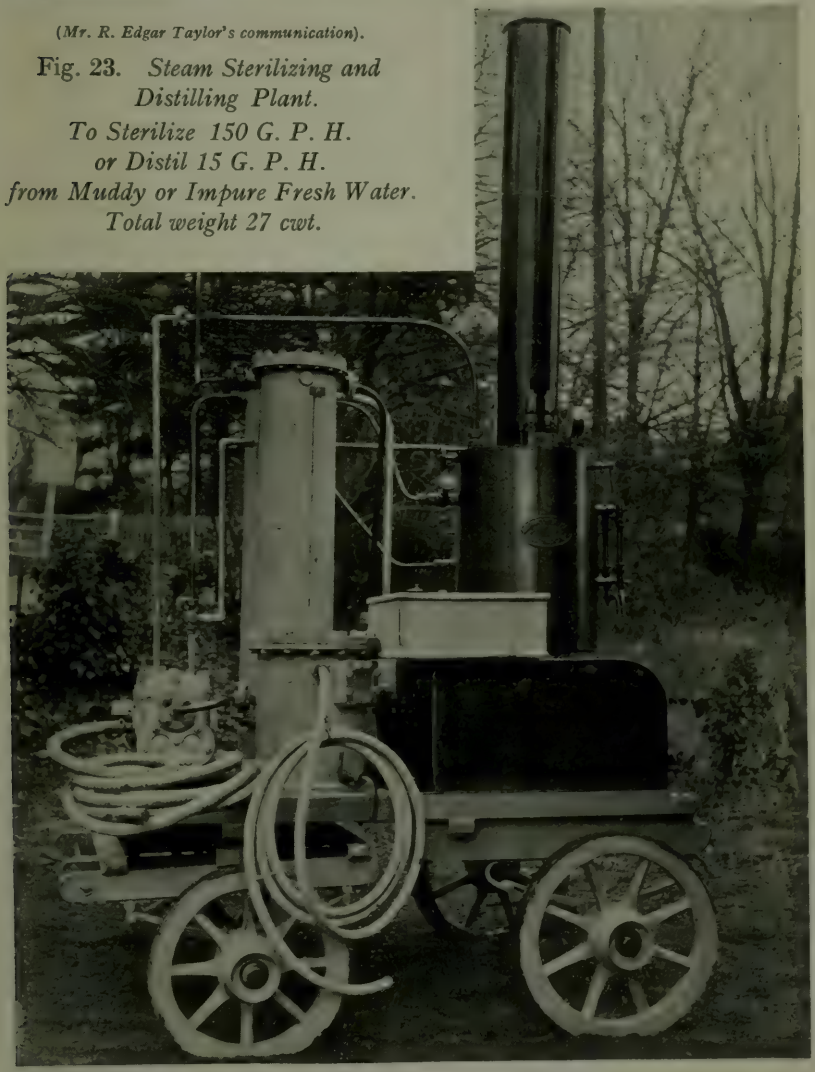
STERILIZATION OF WATER BY CHLORINE GAS. *Plate 25.*

(Captain A. C. Jarvis' communication).

Fig. 22. *Filtration Barge on the Tigris.*

(Mr. R. Edgar Taylor's communication).

Fig. 23. *Steam Sterilizing and Distilling Plant. To Sterilize 150 G. P. H. or Distil 15 G. P. H. from Muddy or Impure Fresh Water. Total weight 27 cwt.*



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